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VALIDATION STUDY OF THE PROPOSED SEVENTH PHASE OF THE SUCHEY-BROOKS AGE ESTIMATION METHOD FOR THE PUBIC SYMPHYSIS

by

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ABSTRACT

The Suchey-Brooks (1990) method for estimating adult age-at-death from the pubic symphysis is widely used and popular among forensic anthropologists. While this technique is quite accurate, it yields wide age interval estimates and is imprecise for individuals aged over fifty years at death. Berg (2008) and Hartnett (2010a) each altered Brooks and Suchey's phase descriptions and added a seventh phase with the goal of increasing precision while maintaining accuracy, especially for older individuals. The hypothesis for this validation study states that the new methods improve the existing Suchey-Brooks method. A total of 384 White Americans (n=213 males and 171 females) aged 26-97 years at death were analyzed at the William M. Bass Donated Skeletal Collection at the University of Tennessee, Knoxville using all three methods. Descriptive statistics, percentages of "correct" age estimates, inaccuracy and bias scores, and rates of inter- and intra-observer agreement were calculated and compared across the three methods. The Hartnett and Suchey-Brooks methods yielded similar percentages of correct estimates for males (85.0% and 84.5% correct, respectively, using ±2 standard deviations from the phase means), although the Hartnett method was significantly less inaccurate ($p<0.001$) and biased ($p<0.001$). The Suchey-Brooks method yielded the highest percentage of "correct" estimates for females aged less than sixty years (100.0%

using ±2 standard deviations or 83.1% using ±1 standard deviation) and was significantly less inaccurate ($p<0.001$) and biased ($p<0.001$) than the Hartnett and Berg methods. The Hartnett and Berg methods were both significantly ($p<0.001$) less inaccurate and biased than the Suchey-Brooks method for females aged over sixty years, but Hartnett's and Berg's scores were not significantly different from each other ($p=0.496$ inaccuracy, $p=0.066$ bias). The Berg method yielded the highest percentage of "correct" estimates for females aged greater than sixty years (90.2% using ±2 standard deviations or 54.5% using ±1 standard deviation). The results of the present study were similar to those obtained by Merritt's (2014) validation study of Hartnett (2010a, b), although Merritt's rates of intra-observer agreement were substantially higher than those calculated for the present study. The hypothesis for the present study was supported.

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CHAPTER 1: INTRODUCTION

Forensic anthropology is a subfield within the larger disciplines of skeletal biology and anthropology. A multidisciplinary approach to forensic casework is critical to allow meaningful integration of theory, standard practices and techniques, and statistical analyses. Novel theories, techniques, and statistical analyses are adopted only after years of testing, debate, and review by experts and practitioners in the field. New theories and techniques penetrate the field slowly due to the extensive time that is necessary for practitioners to learn, understand, and gain experience with the new methods. Validation studies test new methods to confirm their utility to practitioners. The present validation study was undertaken to assess the utility of recent modifications to Brooks and Suchey's (1990) adult age estimation method for the pubic symphysis.

Forensic anthropologists examine skeletonized remains in an effort to reconstruct individuals' lives and deaths. The core of this analysis is the construction of an individual's biological profile. The classic biological profile consists of the individual's sex, age-at-death, stature, and ancestry. Existing or healed pathological conditions and body mass can also be included in the biological profile. Forensic anthropologists present a biological profile to law enforcement to aid in the personal identification of skeletonized remains. Law enforcement officers enter the biological profile of the decedent into a missing persons database and sort through a list of individuals whose biological profiles match or are similar to the decedent's (Algee-Hewitt 2013). The identification of the decedent then allows officers to investigate the individual's disappearance and hopefully return the remains to the next-of kin.

Age-at-death estimation is a crucial element of the biological profile. Age estimation of juveniles relies on analysis of developmental stages, while adult age estimation largely assesses the degeneration of the skeleton. There is a considerable amount of variation in individuals' age-related skeletal degeneration, which makes estimating adults' ages considerably more difficult than estimating the age of juveniles. Methods that are employed to estimate adult age are developed by observing and describing the remains of individuals with documented ages-at-death. The conclusions reached in these studies are then applied to populations as a whole under the assumption that the remains the observer examined to create the method were a fair representation of the individual variation displayed by the entire population. This can create problems if the individuals whose remains were used to generate the method do not effectively represent the populations to which the methods are applied due to genetic or environmental differences (Berg 2008; Djuric *et al.* 2007a; Hartnett 2010a; Hens *et al.* 2008; Schmitt 2004; Schmitt *et al.* 2002). For example, secular change in a population can skew results of analyses by over- or underestimating individuals' ages-at-death (Hoppa 2000). Therefore, age estimation methods that are intended to be applied to modern forensic cases should be developed and tested on samples of recently deceased individuals (UTK 2014).

The Present Study

The present study was undertaken to test the utility of the Suchey-Brooks (1990), Hartnett (2010a), and Berg (2008) adult age estimation methods for the pubic symphysis.

An emphasis was placed on the three methods' efficacy in estimating the age of elderly adults because the primary difference between the Suchey-Brooks method and the two new methods is the new methods' addition of a seventh phase to Brooks and Suchey's six-phase method. The hypothesis of the present study states that the Hartnett and/or Berg methods improve the existing Suchey-Brooks method. This hypothesis was tested by examining a large sample of modern White Americans. To accept the hypothesis, the new methods must increase the percentage of "correct" age estimates or reduce the rates of inaccuracy, bias, or inter- and intra-observer error obtained using the Suchey-Brooks method.

General Types of Adult Age Estimation Techniques

There are three general types of adult age estimation techniques: metric systems, component systems, and phase systems. Metric systems measure or count an age indicator and use the result to calculate an age estimate. Two common metric systems are counting cementum annulations on microscope sections made from tooth roots and measuring the relative height of root translucency in single-rooted teeth (Condon *et al.* 1986; Lamendin *et al.* 1992; Prince and Ubelaker 2002; Stein and Corcoran 1994). Component systems score different components of an age indicator that have been shown to change with age. Scores are then compared to tables listing descriptive statistics for single scores or sums of scores. Component systems have been developed for cranial sutures (Meindl and Lovejoy 1985), the sternal end of the 4th rib (İşcan *et al.* 1984a), the auricular surface (Buckberry and Chamberlain 2002; Lovejoy *et al.* 1985b) and the pubic symphysis (Gilbert and McKern 1973; McKern and Stewart 1957). Phase systems divide a spectrum of age-related changes into arbitrary categories and list age intervals and descriptive statistics for each. Phase descriptions attempt to encompass an age indicator's morphological changes during specific periods of individuals' lifetimes. Popular phase systems include those developed for dental wear (Lovejoy 1985), the sternal end of the 4th rib (Hartnett 2010b; İşcan *et al.* 1984b, 1985), the auricular surface (Lovejoy *et al.* 1985b), and the pubic symphysis (Berg 2008; Brooks and Suchey 1990; Hartnett 2010a; Todd 1920, 1921a).

Problems and Criticisms of Adult Age Estimation

Chronological vs. Biological Age

An individual's chronological age is defined as the number of calendar years since their birth, which is the typical, everyday definition of "age." Biological age, however, refers to the stage of development or degeneration of an individual's body. This is a more nebulous concept since an individual must be compared to a predetermined norm or average to ascertain whether they are "older" or "younger" than normal for their chronological age. Therefore, an individual's chronological age may or may not match their biological age. Biological age is influenced by a number of factors whose impact on the body and its development and degeneration are poorly understood. These include sex, genetics, environment, and pathological conditions and diseases (Berg 2008; Djuric *et al.* 2007a; Ericksen 1991; Gilbert 1973; Hartnett 2010a; Hens *et al.* 2008; Katz and Suchey 1989; Schmitt 2004; Schmitt *et al.* 2002).

Anthropologists estimate biological age from the skeleton under the assumption that biological age and chronological age are closely linked. However, they must attempt to avoid systematic errors caused by this flawed assumption. Many anthropologists advocate the development of population-specific age intervals to reduce error associated with the differences between the biological ages of the study population and the reference population used to create the age estimation method (Djuric *et al.* 2007a; Hens *et al.* 2008; Rissech *et al.* 2012; Schmitt 2004; Schmitt *et al.* 2002).

Statistical Analysis

An age estimate strives to be both accurate and precise. In the context of age estimation, accuracy refers to whether or not an individual's chronological age falls within an estimated age interval. A wider age interval will usually have a higher rate of accuracy because more individuals' chronological ages will fall between its upper and lower limits, while a narrower age interval will have a lower rate of accuracy. However, the need for accuracy must be weighed against the need for precision. Precision is defined as how close the estimate is to the "true" chronological age.[1]

In a forensic context, an anthropologist estimates the age of a decedent to help identify them using missing persons records. The estimated age interval provided by the anthropologist should be wide enough so that the decedent's recorded age falls within the estimated interval and the decedent's missing persons record is therefore not eliminated

[1] Note: Chronological age will henceforth be referred to as "recorded" age and not "true," "actual," or "known" age due to the possibility that individuals' chronological ages have been erroneously reported or recorded.

from the list of possible matches. However, if the estimated age interval is too wide, more missing persons' chronological ages will fall within the interval, making the list of possible matches long and time-consuming to sort through. Therefore, the goal is to provide the narrowest possible age interval that includes the decedent's recorded age. Unfortunately, precision often gets sacrificed for the sake of accuracy when age estimation methods report age intervals associated with scores or phases. Age estimates also become less accurate as individuals age, so wide age intervals are the norm for individuals aged over 40 years.

Error and Bias

In its 1993 ruling on the case of *Daubert v. Merrell-Dow Pharmaceuticals, Inc*., the United States Supreme Court wrote that, "in the case of a particular scientific technique, the court ordinarily should consider the known or potential rate of error." In the field of age estimation, "error" refers to the inaccuracy and bias of an estimate as well as the rates of inter- and intra-observer error associated with a method. Inaccuracy is defined as the absolute distance of an individual's recorded age from a point estimate (Hens *et al.* 2008; Lovejoy *et al.* 1985a, b; Matrille *et al.* 2009; Merritt 2014; Murray and Murray 1991; Schmitt 2004). A point estimate is a single number, such as 35 years, that is used for statistical calculations in lieu of an estimated age interval. Phase means or medians are often employed as point estimates. Bias is similar to inaccuracy, but considers whether the recorded age falls above or below the point estimate. Bias values reveal a method's tendency to over- or underestimate individuals' recorded ages. A common problem in adult age estimation is "attraction to the middle," where methods overestimate the ages of younger individuals and underestimate the ages of older individuals (Algee-Hewitt 2013; Bocquet-Appel and Masset 1982; Brooks 1955; Hens *et al.* 2008; Katz and Suchey 1986).

The term inter-observer error refers to how frequently two or more observers can arrive at the same conclusion, such as a phase assignment for a certain individual. Intra-observer error calculates the consistency of one observer's conclusions during multiple examinations of an individual. Several different statistical techniques can be employed to calculate rates of inter- and intra-observer error, but regrettably there is no consensus within the field of age estimation as to which technique is superior (Algee-Hewitt 2013; Garvin and Passalacqua 2012). Therefore, rates of inter- and intra-observer error are expressed differently by authors examining various age estimation methods, and it is difficult or impossible for readers to directly compare the error rates to ascertain which methods produce the least amount of error.

A lack of uniformity in publication of statistics exists for other calculations as well, including basic descriptive statistics and complex transition analyses (Algee-Hewitt 2013; Berg 2008; Brooks and Suchey 1990; Garvin and Passalacqua 2012; Hartnett 2010a, b). Garvin and Passalacqua (2012) surveyed members of the Physical Anthropology section of the American Academy of Forensic Sciences to find out how different practitioners estimate age-at-death. They asked, "How do you determine an age range once you score a skeletal trait to be of a certain phase/category/component (check all that apply)?" Many respondents (62.2%) reported that they use the age interval presented by the method, while others use the means (32.3%), ± one standard deviation (23.6%), or ± two standard deviations (30.7%). Respondents commented that inconsistencies in the statistics provided by age estimation methods and a lack of standardized practices within the field create confusion among practitioners attempting to estimate age-at-death.

Integration of Multiple Age Estimates

Practitioners agree that employing multiple age indicators to estimate age produces more accurate estimates (Algee-Hewitt 2013; Brooks 1955; Brooks and Suchey 1990; Lovejoy *et al.* 1985a; Scientific Working Group for Forensic Anthropology [SWGANTH] 2013). However, there is no consensus on precisely how to integrate the estimated age intervals yielded by examination of multiple age indicators (Garvin and Passalacqua 2012; Lovejoy *et al.* 1985a; SWGANTH 2013, 2014). Practitioners rely on their experience to varying degrees, which introduces an element of subjectivity and bias to age estimates (Garvin and Passalacqua 2012; SWGANTH 2013, 2014). Some practitioners attempt to minimize this bias by using statistical methods to integrate multiple age estimates (Garvin and Passalacqua 2012; Lovejoy *et al.* 1985a). However, these statistical techniques do not take into account the relative validity of the age estimation methods and indicators used to examine the remains or the appropriateness of the reference samples associated with each method (SWGANTH 2013, 2014). The Scientific Working Group for Forensic Anthropology (2014) recommends the development of robust statistical methods for integration of multiple age estimates.

SWGANTH stresses that new statistical methods should include confidence intervals and rates of error to comply with *Daubert* rulings and to establish standardized practices for age estimation.

Sampling Procedures

The samples utilized by forensic anthropologists to create or test age estimation methods are selected from collections of skeletonized remains that are accessible for scientific research. There are three general types of samples available to researchers: autopsy samples, cemetery samples, and skeletal collections. Autopsy samples have the advantage of representing modern individuals of diverse backgrounds. To be included in the sample, autopsied individuals must have well documented ages-at-death, and researchers in the United States must obtain permission from an individual's next of kin to remove and retain bony tissues legally (Brooks and Suchey 1990; Hartnett 2010a; Katz and Suchey 1986, 1989). Typically, autopsy samples are made up of small skeletal elements such as the pubic bone or sternal rib end that can be easily removed and whose absence does not substantially affect the integrity of the cadaver (Brooks and Suchey 1990; Djuric *et al.* 2007a; Hartnett 2010a, b; Hoppa 2000; İşcan *et al.* 1984a, b, 1985; Katz and Suchey 1986, 1989; Sharma *et al.* 2008; Suchey and Katz 1986). Cemetery samples are useful for creating population standards for historical populations or relatively modern non-American populations (Berg 2008; Godde and Hens 2012; Hens *et al.* 2008; Hoppa 2000; Rissech *et al.* 2012). Records associated with the cemetery are used to establish an individual's sex and age-at-death.

Skeletal collections consist of individuals whose bodies are donated or otherwise obtained by institutions such as universities or museums for teaching or research purposes (Berg 2008; Merritt 2014; Schmitt 2004; Todd 1920; UTK 2014). In some cases unclaimed individuals or indigents whose families chose to donate their bodies in lieu of incurring funeral expenses are included in the collections (Schmitt 2004; Todd 1920). A skeletal collection should reflect a population's sex, age, and ancestry composition so that researchers who examine individuals from that collection can make inferences about the population as a whole. All elements of the biological profile should be well documented for each individual. Personal details such as occupation, socioeconomic status, and history of pathological conditions or drug use are also helpful for answering certain research questions.

A forensic anthropologist needs to be able to accurately estimate the age-at-death of any individual, which means that age estimation research requires samples that include adequate numbers of individuals of all ages. However, the distribution of individuals' ages, also known as a population's or sample's age structure, in samples available for research are such that certain age groups are emphasized, while others are underrepresented. This is problematic because the estimated age structure of a target sample—a sample that consists of individuals with unknown ages-at-death—often, and probably incorrectly, mirrors the age structure of the reference sample used to create the age estimation method (Bocquet-Appel and Masset 1982). Therefore, many anthropologists advocate the formation of population-specific reference samples whose age structures presumably resemble those of the target populations instead of using age estimates derived from reference samples from different regions or time periods (Djuric *et al.* 2007a; Hens *et al.* 2008; Rissech *et al.* 2012; Schmitt 2004; Schmitt *et al.* 2002). New statistical techniques that employ Bayes' Theorem reportedly minimize this type of error (Konigsberg *et al.* 2008).

Forensic anthropologists use adult age estimation methods as part of their construction of an individual's biological profile. Skeletal age indicators are analyzed to estimate an individual's biological age, which is assumed to correspond closely to their recorded chronological age. An estimate is typically expressed as an age interval, such as 30 to 50 years, which should be as narrow as possible but should not exclude the decedent's recorded age. Practitioners consult the statistics presented with age estimation methods to formulate an overall age estimate. The absence of a consensus about which statistics to use and how to integrate age estimates yielded by examination of multiple age indicators has resulted in a lack of standardized practices. Research in the field of adult age estimation is restricted by the availability of samples that practitioners can use to create and test new methods. New methods such as those presented by Berg (2008) and Hartnett (2010a) require extensive testing to be accepted within the field. The present validation study examines the utility of these two new methods compared to Brooks and Suchey's (1990) unmodified method for adult age estimation using the pubic symphysis.

CHAPTER 2: PREVIOUS RESEARCH

Age estimation methods are based on the examination of age indicators—areas of the skeleton that change with individuals' biological age. Changes to an age indicator should occur at predictable rates and individuals should pass through the same sequence of changes at similar biological ages. Forensic anthropologists assess a variety of age indicators to estimate adults' ages-at-death. Adult age estimation methods include microscopic examination of bone and dental tissue (Chan *et al.* 2007; Condon *et al.* 1986; Ericksen 1991; Kerley 1965; Kerley and Ubelaker 1978; Liu *et al.* 1999; Matrille *et al.* 2009; Singh and Gunberg 1970; Stein and Corcoran 1994; Stout and Paine 1992; Thompson and Galvin 1983) and gross morphological inspection of dentition (Lovejoy 1985), cranial sutures (Meindl and Lovejoy 1985), epiphyseal fusion in young adults (Albert and Maples 1995; Suchey 2006; Webb and Suchey 1985), the sternal end of the 4th rib (Hartnett 2010b; İşcan et al. 1984a, b, 1985), the acetabulum (Calce 2012; Rouge-Maillart *et al.* 2004), the auricular surface of the ilium (Buckberry and Chamberlain 2002; Lovejoy *et al.* 1985b), and the pubic symphysis (Berg 2008; Brooks and Suchey 1990; Gilbert and McKern 1973; Hartnett 2010a; McKern and Stewart 1957; Todd 1920, 1921a). These methods all have advantages and disadvantages, yet often one or more of these age indicators does not survive postmortem taphonomic changes (Brooks and Suchey 1990; Buckberry and Chamberlain 2002; McCraw 2014). It is crucial to assess as many age indicators as possible to increase the accuracy and precision of the overall age estimate (Algee-Hewitt 2013; Brooks 1955; Brooks and Suchey 1990; Lovejoy *et al.* 1985a; McKern and Stewart 1957; SWGANTH 2013). Multifactorial statistical analyses can be employed to integrate the age estimates yielded by examination of multiple age indicators, although these analyses assume that each age indicator and the age estimation method associated with it are equally useful and valid (Algee-Hewitt 2013; Lovejoy *et al.* 1985a). Many practitioners rely instead on their experience, the overall "gestalt" of the remains, or the descriptive statistics and age intervals presented by age estimation methods to formulate an overall age estimate (Garvin and Passalacqua 2012).

Histology

Microscopic examination of bone tissues can be helpful for age estimation in the case of isolated bone fragments or damaged remains, but should be limited in the case of complete and undamaged remains due to its destructive nature (Chan *et al.* 2007; Matrille *et al.* 2009). Histological techniques are based on assessment of bone remodeling, which occurs throughout life, particularly in response to mechanical stress (Chan *et al.* 2007). Kerley's (1965) original technique analyzed samples taken at the midshaft of the femur, tibia, and fibula. The number of osteons, osteon fragments, and non-Haversian canals are counted, and the percentages of lamellar bone in four 100x fields are estimated. An age estimate is calculated by applying these values to regression formulae provided. Kerley designed this histological technique with the intention of minimizing error and maximizing repeatability, even for inexperienced practitioners. However, Kerley and Ubelaker (1978) revised Kerley's (1965) regression formulae and microscope field size specifications due to systematic errors encountered by Ubelaker. Other modifications to the Kerley (1965) method suggested better sampling locations and procedures to obtain more accurate age estimates (Chan *et al.* 2007; Matrille *et al.* 2009). Singh and Gunberg (1970) examined the mandible, femur, and tibia, and included the number of lamellae per osteon as well as the diameter of Haversian canals in their analysis. They reported high rates of accuracy and precision, especially for the mandible. Thompson and Galvin (1983) presented new regression formulae for estimating the ages-at-death of adults aged less than 55 years using samples from the tibia. They found no significant histological differences in sex or ancestral groups. Ericksen (1991), however, reported that sex-specific equations produced more accurate age estimates than combined-sex equations for samples from the anterior diaphysis of the femur. Stout and Paine (1992) examined samples from the ribs and clavicle and concluded that their regression formula that included values from both bones was more accurate than their formulae for the individual bones. Recent technological advances in computer imaging and analysis allow for reliable analyses of large sample sizes, which will further improve histological age estimation techniques (Liu *et al.* 1999; Matrille *et al.* 2009).

Dentition

Teeth are useful for estimating age, particularly when remains consist of a skull or dentition in isolation. Dentition resists postmortem taphonomic changes and is also valuable for personal identification when antemortem dental records are available for analysis. The age of juveniles can be estimated very accurately by analyzing the development and eruption of deciduous and adult dentition (AlQahtani *et al.* 2008; Buikstra and Ubelaker 1994; Moorrees *et al.* 1963). However, age estimation methods based on tooth development and eruption are no longer relevant after the third molars have fully developed in early adulthood. Adult age estimation techniques for middle-aged and elderly adults include gross examination or measurement of dental wear (Brothwell 1963; Lovejoy 1985; Mays *et al.* 1995), computation of the sum of pararadicular cementum annulations in tooth roots (Condon *et al.* 1986; Stein and Corcoran 1994), and measurement of root translucency in single-rooted teeth (Lamendin *et al.* 1992; Prince and Ubelaker 2002). Assessment of dental wear is more practical for ancient or historical populations than modern populations due to the absence of abrasive particles in food after the industrial revolution, which minimizes dental wear (Lovejoy 1985). Cementum annulations and root translucency are valuable age indicators due to the durability of tooth roots (Stein and Corcoran 1994). These age estimation techniques are predicated on the presence of the dentition in a relatively healthy state; antemortem or postmortem tooth loss, periodontal disease, or extensive dental disease affect the integrity of the dentition and thus its utility as an age indicator.

Dental Wear

Patterns of dental wear can be useful to estimate adult age-at-death, particularly for archaeological or historical populations due to the regular presence of abrasive particles in food during these eras (Lovejoy 1985). Methods of age estimation using dental wear typically take two forms: measuring crown height or gauging the pattern and extent of crown loss. Mays *et al.* (1995) used digital calipers to measure the crown heights of left maxillary and mandibular molars of individuals in a cemetery population from the United Kingdom to evaluate the age estimation method created by Brothwell (1963). They confirmed the utility of Brothwell's technique but suggested some modifications, and provided some general rules about differentiating young adults from middle-aged and elderly adults based stage of tooth wear (Mays *et al.* 1995). Lovejoy (1985) published a phase system where the patterns of dental wear on the maxillary and mandibular dentition are observed and matched to an appropriate phase, which corresponds to an age interval. He developed this method using an archaeological population of Native Americans at the Libben site in northern Ohio, and found that dental wear was a reliable age indicator. Fortunately, these methods are useful for archaeological populations, because teeth are likely to resist degradation and because people alive before the industrial revolution consumed abrasive food on a regular basis, so their teeth wore down at predictable rates (Lovejoy 1985). However, extensive antemortem tooth loss or dental disease in an individual or population can hinder analyses of dental wear (Mays *et al.* 1995).

Cementum Annuli

The thickness of the layer of cementum on the roots of teeth is approximately proportional to the age of the tooth (Condon *et al.* 1986; Stein and Corcoran 1994). Methods for human age estimation using pararadicular cementum annulations have been adapted from existing zoological techniques for estimating the age of animals such as caribou, moose, elk, deer, bison, red fox, and nonhuman primates (Condon *et al.* 1986; Stein and Corcoran 1994). The cementum layers, or annulations, are counted, and the total is added to the estimated age of eruption of the tooth to calculate an approximate age. The location of cementum annulations on the tooth root is advantageous, because the root is less susceptible to taphonomic degradation than the crown (Stein and Corcoran 1994). However, this method requires destruction of the tooth, and its accuracy is reduced when the tooth is affected by dental or periodontal disease (Condon *et al.* 1986).

Root Translucency

Lamendin *et al.* (1992) presented a new method for estimating adult age using single-rooted teeth that they developed on a modern French population with known ages-at-death. They calculated age using measurements of the height of periodontosis, also known as gingival regression, from the cementoenamel junction and the height of root translucency from the apex of the tooth in comparison to total root height. Root translucency is caused by the deposition of hydroxyapatite crystals in the dentin tubuli over time, and is best viewed by placing the tooth on a light box (Lamendin *et al.* 1992; Prince and Ubelaker 2002). Lamendin *et al.* (1992) caution that root translucency does not appear before the age of 20 years and is therefore only useful for individuals aged 20 years or greater. They also warn that error rates are high for some individuals aged less than 40 years and greater than 80 years. Prince and Ubelaker (2002) tested the Lamendin technique on a sample of American Whites and Blacks from the Terry Collection at the Smithsonian. They found that the method was applicable to American populations, but the method is subject to inter-observer error based on varied interpretations of the features described. As reported by Lamendin *et al.* (1992), Prince and Ubelaker (2002) found that for unknown reasons the rates of error are significantly elevated for some individuals. This technique is not applicable to remains where single-rooted teeth are absent, and isolated teeth are of limited value in an archaeological context. However, an age estimate using an isolated tooth in a forensic context is useful for narrowing down a list of possible matches to missing persons so that the tooth can be used for DNA analysis or comparison with antemortem dental records.

Cranial Sutures

Cranial sutures slowly obliterate with age, making them a potentially useful indicator of age-at-death. This method is especially valuable when only a cranium or fragments of a cranium are presented to an anthropologist for analysis. Anatomists have recognized the utility of cranial suture closure as an age indicator since the 16th century, and suture closure was studied intensively during the first half of the 20th century (Meindl and Lovejoy 1985). However, in the latter half of the 20th century the method fell out of favor due to findings that indicate that suture closure is subject to a high degree of individual variation (Brooks 1955; Garvin and Passalacqua 2012; McKern and Stewart 1957; Meindl and Lovejoy 1985). The technique employed by Meindl and Lovejoy (1985) scores the closure of ecto- and endocranial sutures at various locations on the cranial vault. Scores range from 0, “no evidence of any ectocranial closure at the site,” to 3, where the suture is completely obliterated (Meindl and Lovejoy 1985:58). The sum of the scores is used to generate an age estimate. Unfortunately, the variability of the timing and extent of suture closure means that age estimates generated using only this method should be avoided (Acsádi and Nemeskéri 1970; Brooks 1955; Galera *et al.* 1998; McKern and Stewart 1957; Meindl and Lovejoy 1985).

Fusion of Epiphyses

An important age indicator for juveniles and young adults is the extent of epiphyseal union at various locations on the skeleton. Suchey (2006) reported that fusion of any long bone epiphysis indicates an age of at least 14 years for females and at least 16 years for males. She also provided upper limits of age intervals for males and females if certain long bone epiphyses are not fused. Albert and Maples (1995) created a method where they used four stages of fusion of the epiphyses of vertebral centra to estimate the age of older juveniles and young adults. They provide upper and lower limits for each stage of fusion; the youngest male and female to show complete fusion of all epiphyses on all thoracic vertebrae and the first two lumbar vertebrae were 24 years 2 months and 25 years, respectively. Webb and Suchey (1985) presented ages at which the anterior iliac crest and the medial clavicle fuse in American males and females. They separated fusion into four categories: nonunion with no epiphyses, nonunion with separate epiphyses, partial union, and complete union. Upper limits for nonunion with no epiphyses, age intervals for partial union, and lower limits for complete union for the anterior iliac crest and the medial clavicle are given for both sexes (Webb and Suchey 1985). Males' epiphyses tend to fuse later than females', but in all individuals of both sexes the medial clavicle is fused by the age of 31 years (Suchey 2006; Webb and Suchey 1985). These methods are useful for estimating the ages of older juveniles and young adults, but once all epiphyses are fused, they provide only lower age limits. In addition, epiphyses are often lost or decompose after death (McCraw 2014; Pokines 2014), so an individual whose epiphysis had not formed would appear to be in the same developmental stage as an individual whose epiphysis was present but not fused if the unfused epiphysis was lost postmortem.

Fourth Rib

İşcan *et al.* (1984a) presented a new adult age estimation technique which scored three components of the sternal end of the right fourth rib. They developed the method using a sample of sternal rib ends that were removed from 93 White males at autopsy (İşcan *et al.* 1984a). Pit depth, pit shape, and rim and wall configurations were scored on scales of 0-5, and each score and the sum of the scores can be compared to a table listing the descriptive statistics and age intervals of each score and sum to arrive at an age estimate. The 95% and 100% age intervals associated with sums of scores showed considerable overlap and their standard deviations ranged from 0.0-13.2 years. İşcan *et al.* (1984a) reported that males aged 20-29 years could be estimated accurately to within two years of their recorded ages while males aged 50-69 years could have their ages-at-death estimated to within seven years using this new method. İşcan *et al.* (1984b) revised their original method by modifying it from a component system to a phase system applicable to White males and females (İşcan *et al.* 1984b, 1985). The system employed nine phases which described the original three components as well as bone texture and quality. Age interval overlap was minimal using 95% intervals but was extensive using

100% intervals. İşcan *et al.* (1984b) found that the accuracy of their phase method was similar to methods using the pubic symphysis (Gilbert and McKern 1973; McKern and Stewart 1957; Todd 1920, 1921a) but better than methods employing cranial sutures (Brooks 1955; McKern and Stewart 1957) to estimate age. Their measure of accuracy is unclear but may have to do with the methods' standard deviations, which are similar to those published by McKern and Stewart (1957) and Gilbert and McKern (1973) (İşcan *et al.* 1984b:1103). Tests of the İşcan *et al.* (1984b, 1985) method were undertaken to analyze inter-observer error (İşcan and Loth 1986a, b). Each test allowed over twenty observers with varying levels of experience to examine small samples of ribs and assign them to a phase using only the photographs that accompanied the phase descriptions published by İşcan *et al.* (1984b, 1985). İşcan and Loth (1986a, b) found that level of experience did not affect error and that observers averaged within one phase of the "ideal" phase assignment. Exemplary casts are now available to accompany the phase descriptions. Sternal rib ends are fragile and do not preserve well after death (Brooks and Suchey 1990; Pokines 2014), but Aktas *et al.* (2004) found that İşcan *et al.*'s (1984b, 1985) methods can be applied to right and left 3rd, 4th, and 5th ribs in case the 4th rib is absent or it is difficult or impossible to differentiate the individual ribs.

Acetabulum

Rouge-Maillart *et al.* (2004) presented an adult age estimation method that scored four criteria of the acetabulum. They argued that, like the auricular surface, the acetabulum is robust and resists postmortem taphonomic changes (Lovejoy *et al.* 1985b;

McCraw 2014). Rouge-Maillart *et al.* (2004) examined the acetabular rim, the acetabular fossa, the articular crescent, and apical activity at the posterior cornu of the articular crescent in thirty male individuals. The acetabular rim is blunt in young adults and becomes sharpened, develops osteophytes, and experiences generalized destruction with advanced age. The bone of the acetabular fossa and the articular crescent is dense in young adults but appears micro- and macroporous in older adults. Apical activity increases with age due to the formation of osteophytes at the posterior cornu. Rissech *et al.* (2006) examined 242 males and added five criteria to those of Rouge-Maillart *et al.* (2004). Rissech *et al.* (2006) agreed that porosity in the acetabular fossa and apical activity changed with age, but found that the acetabular groove, acetabular rim shape and porosity, the outer edge of the acetabular fossa, and activity or depression of the acetabular fossa experienced age-related changes as well. The authors presented means and variances for each score associated with each of the seven variables they identified and reported 89% accuracy using ten-year age intervals and 67% using five-year intervals. Calce (2012) simplified Rissech *et al.*'s (2006) method by identifying the three variables that were most correlated with age, employing three broad age intervals, and allowing the use of the method for both sexes. The three variables isolated by Calce (2012) were the groove along the acetabular rim, osteophyte development at the acetabular rim, and apical growth at the posterior cornu of the articular crescent. Calce separated individuals into three age intervals: young adults aged 17-39 years, middle-aged adults aged 40-64 years, and older adults aged 65 years or greater. She reported an accuracy rate of 81% and moderate to substantial inter- and intra-observer agreement.

Calce recommended that the utility of her technique be tested on non-White and archaeological populations that were not included in her sample.

Auricular Surface

Lovejoy *et al.* (1985b) created a method for estimating adult age using the auricular surface of the ilium. Their intention was to formulate a method using a skeletal element that was more likely to survive postmortem taphonomic changes than the pubic symphysis, which is frequently damaged postmortem (McCraw 2014), and that continued to show distinguishable age-related changes after the age of 50 years. Lovejoy *et al.* (1985b) found that their eight phase descriptions corresponded well to observations made by an anatomist who comprehensively studied the histology of the cartilage at the sacroiliac joint. They hypothesized that the changes to the cartilage of the joint directly relate to the morphology of the bone. The eight phases defined by Lovejoy *et al.* (1985b) include remarks on the grain and density of the bone, micro- and macroporosity, billowing, striations and transverse organization, the appearance of the apex, and retroauricular activity.

The age intervals for Lovejoy *et al.*'s (1985b) phases I-VI are expressed in increments of five years for individuals aged 20-49 years, and phases VII and VIII have intervals of 50-59 years and 60+ years, respectively. No descriptive statistics accompany the phase descriptions, although the authors include the "modal ages" of individual auricular surfaces shown in figures. Lovejoy *et al.*'s (1985b) age intervals do not overlap despite the contemporary acceptance and use of overlapping age intervals for age estimation methods (Brooks 1955; Gilbert and McKern 1973; McKern and Stewart 1957). Brooks (1955) found that the percentage of correct estimates using Todd's (1920, 1921a) technique increased dramatically using overlapping age intervals. Two later methods using the pubic symphysis—McKern and Stewart (1957) and Gilbert and McKern (1973)—both used age intervals that overlapped significantly.

Buckberry and Chamberlain (2002) noted that the five-year age intervals presented by Lovejoy *et al.* (1985b) were "optimistically narrow," but rectified this issue with their conversion of the Lovejoy *et al.* (1985b) method from a phase system to a component system. They argued that confusion could arise when using the Lovejoy *et al.* (1985b) method because characteristics of multiple phases could appear in a single auricular surface. Therefore, Buckberry and Chamberlain (2002) scored five separate components of the auricular surface: transverse organization, surface texture, microporosity, macroporosity, and apical changes. They provided descriptive statistics for different sums of component scores and associated each sum with a Lovejoy *et al.* (1985b) phase so that their statistics could be applied when using either the phase system or component system to estimate age. The authors felt that their wide age intervals that overlapped significantly were more realistic than those presented by Lovejoy *et al.* (1985b), and their range of standard deviations (1.53-14.47 years) was similar to those reported by other age estimation studies (Brooks and Suchey 1990; İşcan *et al.* 1984a, b, 1985). Buckberry and Chamberlain found an insignificant rate of intra-observer error and a weighted Kappa statistic of 0.66 when measuring inter-observer agreement, which Landis and Koch (1977:165) classify as "substantial" agreement.

Pubic Symphysis

Overview

In the early 1920s, anatomist T. Wingate Todd (1920, 1921a) comprehensively described the morphological changes seen in the adult pubic symphysis. Brooks (1955) tested Todd's method on a collection of Californian Native Americans with some success and made suggestions for its modification. McKern and Stewart (1957) and Gilbert and McKern (1973) created three-component techniques to be used for males and females, respectively.

Meindl *et al.* (1985) presented a review of the existing age estimation methods that employed the pubic symphysis as an age indicator. They found that Todd's (1920, 1921a) method, including some adjustments proposed by Brooks (1955), was more accurate than the component systems designed by McKern and Stewart (1957) and Gilbert and McKern (1973). Katz and Suchey (1986) collapsed Todd's ten phases into six phases. Brooks and Suchey more thoroughly described the six phases of the "Suchey-Brooks method" in a later article (Brooks and Suchey 1990). The Suchey-Brooks method has become the most popular technique used to estimate adult age from the pubic symphysis and has been tested on many collections around the world (Garvin and Passalacqua 2012; Hens *et al.* 2008; Hoppa 2000; Schmitt *et al.* 2002). Recently, Berg (2008) and Hartnett (2010a) proposed the addition of a seventh phase to the Suchey-Brooks method to more accurately estimate the age of older adults. Each redefines other phases to allow for the inclusion of a seventh phase (Berg 2008; Hartnett 2010a). The present study tests the utility of Berg's and Hartnett's methods in comparison to the unmodified Suchey-Brooks method.

The Todd Method

Nineteenth century anatomists recognized the variability of the pubic symphysis and noted that its morphology changes over the course of an individual's life (Todd 1920). Todd (1920) was one of the first anatomists to recognize the need to identify areas of the human skeleton that change with advancing age and their application to anthropology (Algee-Hewitt 2013). Furthermore, he understood the problems that continue to plague age estimation techniques such as the need for well-documented modern skeletal collections and meaningful skeletal age indicators, the impact of pathological changes on skeletal age indicators, individual variation, erroneous reporting of age, sex and ancestry differences, utility of employing multiple age indicators, and the overall difficulty of estimating adult age, even for experienced practitioners. Todd (1920, 1921a) argued that the pubic symphysis is a useful skeletal age indicator for adults aged 20 to 40 years. Todd (1921b, c) subsequently compared human and animal pubic symphyses and looked at whether the phase of a pubic symphysis could be determined by viewing radiographically (Todd 1930).

Around 1912, Todd and his colleagues in the Anatomical Library at Western Reserve University began a skeletal collection by acquiring the cadavers of deceased patients from local hospitals. They obtained the patient's hospital and civil records, measured the decedent upon arrival at the anatomical laboratory, macerated the skeleton, and then labeled, measured, and stored the bones. The collection included American- and foreign-born Whites and American Blacks, with more Whites than Blacks and more males than females. Todd (1920) noted that there was a tendency for recorded ages to cluster around multiples of five, which he attributed to individuals' lack of knowledge of their chronological age and/or poor record-keeping.

Todd (1920) first examined the pubic symphyses of 306 White males in the collection at the Anatomical Laboratory. He sorted individuals into groups based on recorded chronological age, i.e., separate groups for individuals aged 34, 35, and 36 years, etc., and formulated phases based on where he felt morphological changes occurred between age groups. Todd advanced the hypothesis that the ossific nodule sometimes seen in phases I-V is a form of epiphysis, which he further described (1921c, 1923). The age intervals for nine of his ten phases are quite narrow; for example, phase I is 18-19 years and phase IX is 45-50 years (Todd 1920). However, the age interval for phase X is 50+ years, and Todd noted that disfigurement increases with age and briefly mentioned the breakdown of the symphyseal rim and the formation of osteophytes (Todd 1920). His phase age intervals do not overlap, except in the cases of phases VII and VIII, whose age intervals are 35-39 years and 39-44 years, respectively. Some individuals fell into two consecutive phases, which Todd did not seem to find problematic. However, if an individual fell into a phase that was markedly separated from their appropriate chronological age interval, then Todd attributed the misclassification of that individual to an "accelerated" or "retarded" rate of morphological change instead of acknowledging a wider range of normal variation.

Todd (1921a) compared his results obtained with the White males in his previous (1920) study to samples made up of White females and American Black males and females. Todd's sample sizes for these three groups were smaller: 90 Black males, 47 White females, and 22 Black females. These samples had similar problems with finding accurate "known" ages; the ages of patients as recorded by hospital staff were approximate, so Todd reviewed individuals' stage of epiphyseal union and tooth wear to make sure that their recorded chronological age was near their biological age. He hypothesized that ancestry and sex differences affect the timing, progression, and morphology of the changes seen in the pubic symphysis.

Todd (1921a) found that the timing of pubic symphysis changes in White and Black males and in White males and females varies slightly, but that all individuals go through the same phases in the same order. Again, he attributed individuals whose recorded ages did not match their pubic symphysis phase to instances of "acceleration" or "retardation" of age-related changes. Todd noted that examination of different skeletal elements sometimes yielded divergent age estimates and that single age indicators or the entire skeleton can display accelerated or retarded rates of change. Due to small sample sizes, each phase consisted of very few individuals, and female samples are described with reference to male samples due to exceptionally small sample sizes. No descriptive statistics are provided, presumably due in part to Todd's assertion that individuals that vary from what he considered the norm, i.e., within about five years above or below their recorded age, are abnormal. Todd seems to have believed that larger age intervals for each phase were not merited, because individuals with accelerated or retarded rates of change did not represent normal variation.

Component Systems

McKern and Stewart (1957) created a three-component technique for estimating age-at-death from the pubic symphysis for males using a sample of 450 American males aged 17-50 years who died in the Korean War. All individuals had recorded ages except 75 individuals who were never identified. Most individuals were between 18 and 23 years old at death, and over 90% were White. McKern and Stewart (1957) analyzed the dorsal plateau, the ventral rampart, and the symphyseal rim using casts of pubic symphyses that Stewart created while assessing the sample in Japan in 1954. Each component was scored on a scale of 0-5, and the authors presented tables with descriptive statistics for each score and the sums of scores. Instructions and copies of casts that demonstrated each score for each component were made available to practitioners after the publication of McKern and Stewart's (1957) report. The limited age of the sample employed to develop this method is reflected in the descriptions of the morphological changes: a lack of middle-aged and elderly adults led to minimal description of the degeneration of the symphyseal face. Snow (1983) published mathematical equations for the McKern and Stewart (1957) method that analyze the three scores together instead of separately, which facilitates age estimation. Sharma *et al.* (2008) analyzed the pubic symphyses of 336 individuals that had been removed at autopsy in India using the

McKern and Stewart (1957) method and found that it was not useful for estimating the ages-at-death of individuals aged over 40 years.

Gilbert (1973) warned against using the McKern and Stewart (1957) method for females due to differences in the timing of symphyseal changes in males and females. After examination of 180 females aged 17-55 years, Gilbert and McKern (1973) rectified this issue by publishing statistics to be used for females when scoring them in the same manner as McKern and Stewart (1957). They noticed that birth trauma only minimally affected the pubic symphysis and its utility as an age indicator for females. They did note that their analyses yielded “disappointingly high” standard deviations, which ranged from 2.00-9.00 years (Gilbert and McKern 1973:37). However, this range of standard deviations was not dissimilar to McKern and Stewart’s range of 0.49-6.22 years. Age intervals for the sums of scores showed considerable overlap in both methods. McKern and Stewart (1957) reported accuracy rates of around 90% for observers who had some minimal experience with their method, but Gilbert and McKern (1973) did not present an accuracy rate.

The Suchey-Brooks Method

Suchey (1979) detailed the difficulties in using the Gilbert and McKern (1973) method to estimate adult female age from the pubic symphysis. She discussed the problems with colleagues and found that she was not the only practitioner who had encountered difficulties with the method. She performed a small study by having 23 members of the Physical Anthropology section of the American Academy of Forensic

Sciences use the Gilbert and McKern (1973) method to assess eleven pairs of pubic symphyses that she obtained from the Los Angeles County Coroner's office (Suchey 1979). While practitioners with more experience were able to estimate individuals' ages more accurately, there was a large degree of error. Based on these results, Suchey began to collect more pubic symphyses from the LA Coroner with the intention of modifying previous methods or creating a new method to more accurately estimate adult age using the pubic symphysis.

By 1986, the collection of pubic symphyses amassed by Suchey and her colleagues contained over 1500 individuals aged 14-99 years from a variety of socioeconomic and ancestral backgrounds (Suchey and Katz 1986). Katz and Suchey (1986) found that the Todd (1920) and McKern and Stewart (1957) methods performed poorly when 26 forensic practitioners scored 739 male pubic symphyses. Katz and Suchey (1986) collapsed Todd's (1920; 1921a) ten phases into six phases, because practitioners could not reliably differentiate certain phases; for example, they combined Todd's phases I-III into a single phase. They calculated means, standard deviations, and 95% age intervals for the six modified phases. This study found that all methods performed poorly for older individuals, but they reported that the six-phase method substantially improved the accuracy of age estimates for individuals aged less than 40 years.

The seminal paper that fully described the Suchey-Brooks method was published in 1990, and was based on analysis of 1225 individuals aged 14-99 years at death (Brooks and Suchey 1990). Brooks and Suchey critiqued the publication "Recommendations for

Age and Sex Diagnoses of Skeletons" produced by the Workshop of European Anthropologists (1980). This publication recommended two European papers for age estimation, both of which had been formulated with reference to the work of Todd (1920, 1921a), Brooks (1955), and McKern and Stewart (1957), but had neglected to include the Gilbert and McKern (1973) paper for estimating the age of females (Brooks and Suchey 1990). Brooks and Suchey (1990) argued that one of the methods included in the "Recommendations for Age and Sex Diagnoses of Skeletons," described by Acsádi and Nemeskéri (1970), was complex and statistically flawed. As an alternative, Brooks and Suchey provided a description of their new method, which used the six modified and condensed phases proposed by Katz and Suchey (1986). Phase descriptions were the same for both sexes, but Brooks and Suchey presented separate descriptive statistics for each sex, including means, standard deviations, and 95% age intervals for each phase. The histograms used to illustrate the ages of individuals in each phase effectively demonstrated the reason for the wide age intervals provided for most phases: individuals in phases I and II cluster close together in an approximation of a normal curve, while phases III and IV are more skewed, and phases V and VI are spread out over many decades (reproduced in Figure 2.1) (Brooks and Suchey 1990:236). Brooks and Suchey posited that the descriptive statistics presented could be used in forensic and historical cases due to the diverse socioeconomic and racial background of the sample. However, for historic samples with unknown ages-at-death they recommended using phases I and II as upper limits for the ages of young adults and phases V and VI as lower limits for elderly adults instead of employing the precise age intervals provided in their tables. The authors also advised the use of multiple age indicators where available.

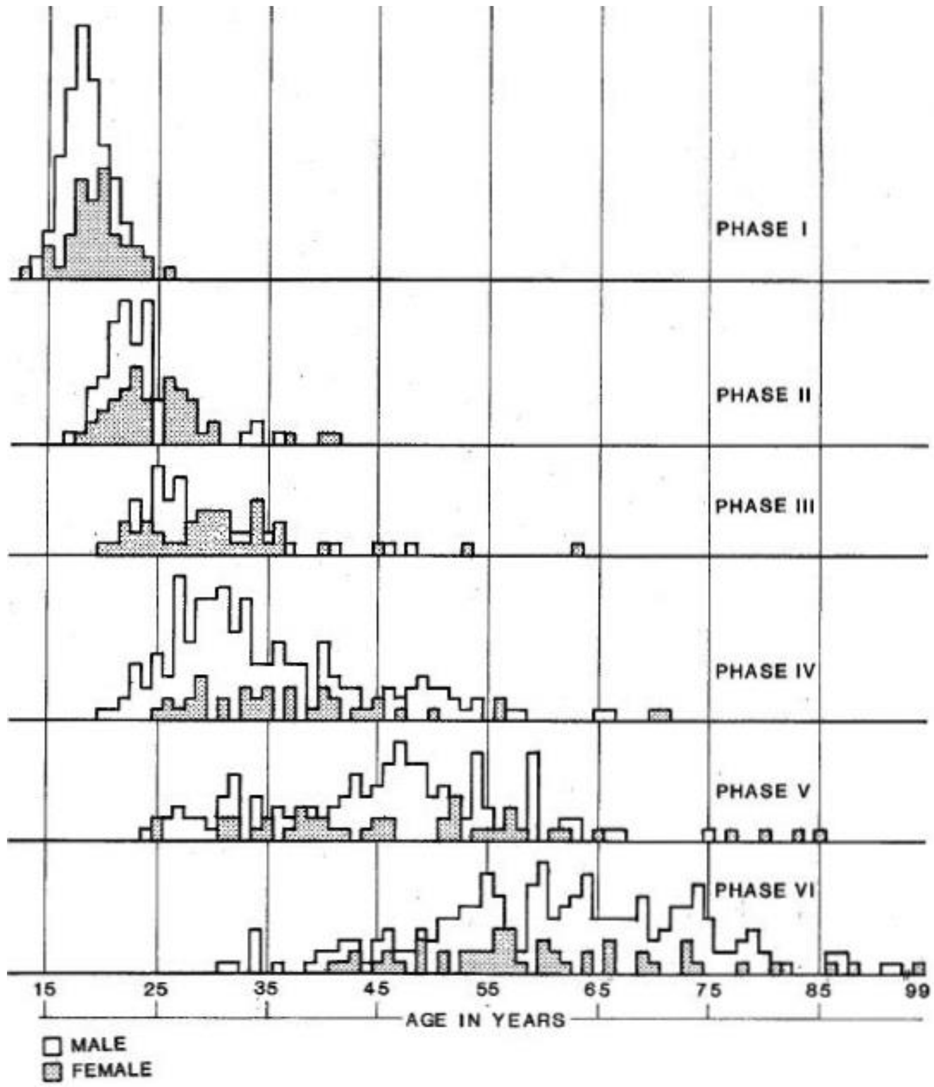

Figure 2.1. Histograms comparing the age distribution of the female sample to the male sample used in Brooks and Suchey (1990:236).

Tests of the Suchey-Brooks Method

The Suchey-Brooks method has gained worldwide acceptance, although many practitioners agree that population-specific statistics are required for areas outside the

United States (Djuric *et al.* 2007a; Hens *et al.* 2008; Rissech *et al.* 2012; Schmitt 2004; Schmitt *et al.* 2002). A number of studies have been performed to test the Suchey-Brooks method on populations in Europe, Africa, and Asia. Hoppa (2000) compared the Suchey-Brooks (1990) method to the McKern and Stewart (1957) and Gilbert and McKern (1973) methods using modern American populations and an 18th and 19th century archaeological sample from the Spitalfields collection in the United Kingdom. He found that the Suchey-Brooks method performed better than the component methods and that there were population differences in the timing of age-related changes. Godde and Hens (2012) also found discrepancies in the timing of age-related changes to the pubic symphysis when they compared collections from the United States, the Balkans, and Italy, which they attributed to "different within phase age-at-death distributions that reflect differences in aging between the populations" (Godde and Hens 2012:259). Hens *et al.* (2008) and Rissech *et al.* (2012) examined collections from Italy and Spain, respectively, and found that in both populations the rates of inaccuracy increase with age of the specimen. Schmitt *et al.* (2002) used a large, combined sample from Portugal, Switzerland, South Africa, Thailand, the United Kingdom, and the United States to investigate the relative merits of the pubic symphysis and the auricular surface as age indicators. They found that the auricular surface performed better than the pubic symphysis and better singly than in combination with the pubic symphysis. Schmitt (2004) and Djuric *et al.* (2007a) found that the Suchey-Brooks method tended to underestimate the ages-at-death of elderly adults in Thailand and the Balkans, respectively. Djuric *et al.* (2007a) suggested modifications to the Suchey-Brooks method to be used in future studies in the Balkans, while Schmitt (2004) recommended not using the method on Asian populations due to the substantial environmental and genetic differences between American and Thai populations.

Berg (2008)

Berg (2008) modified the Suchey-Brooks (1990) method and added a phase VII to incorporate changes to the pubic symphysis in elderly females due to osteoporosis. His first sample consisted of 85 female genocide victims from the Balkans whose remains had been identified by relatives. The second sample Berg used was composed of 104 American females from the William M. Bass Donated Collection. There were 56 individuals over 40 years old in the Balkan sample and 94 individuals over 40 years old in the Bass Collection sample. Individuals over 40 years old were isolated from the larger samples and sorted into three groups based on their morphology. These three groups would later be designated phases V, VI, and VII. Preliminary descriptions for these three phases were written, and the samples were sorted again using the new definitions. After the second sorting, phase definitions were refined, and the use of a standard hand-held magnifying glass was permitted. Three volunteers then used the new definitions for phases V-VII as well as the definitions of phases I-IV from the Suchey-Brooks method to sort the samples into groups. Inter- and intra-observer error rates were calculated, as well as means and standard deviations for phases IV-VII. A Bayesian transition analysis was performed to ascertain the degree of overlap between phases, and he found that all phases were distinct. Berg reported low rates of inter- and intra-observer error and improved accuracy with his modified descriptions of phases V and VI and his added phase VII than with the unmodified Suchey-Brooks phases.

Hartnett (2010a)

Hartnett (2010a) used an autopsy sample from the Forensic Science Center in Phoenix, Arizona to redefine all six Suchey-Brooks pubic symphysis phases and add a phase VII. Her sample consisted of 626 individuals (419 males and 211 females) aged 18 to 99 years at death whose next of kin had given permission to remove the pubic symphyses and sternal ends of the right 4th rib. Hartnett and two volunteers scored the pubic symphyses using the Suchey-Brooks method and then sorted specimens into seven groups based on their morphological characteristics. The seven groups were used to create phase definitions, and descriptive statistics were calculated for each phase. Hartnett noted the large amount of variation in the progression of age-related changes to the pubic symphysis and mentioned that this was the reason for giving wide age intervals when estimating adult age, especially in older individuals. Hartnett also reported low rates of inter- and intra-observer error using her modified method.

Comparison of Brooks and Suchey (1990), Hartnett (2010a), and Berg (2008) Phase Descriptions

The descriptions of the morphological changes seen in the pubic symphysis published by Brooks and Suchey (1990), Hartnett (2010a), and Berg (2008) are all similar (Table 2.1). However, Hartnett and Berg emphasize various characteristics to differentiate phases V-VII. Berg (2008) does not modify Suchey-Brooks phases I-IV.

Hartnett's definitions include notes about the overall quality and texture of the bone as well as the presence or absence of dorsal lipping, ligamentous outgrowths on the ventral surface, and bone spicules on the medial edge of the obturator foramen (Hartnett 2010a). The Suchey-Brooks (1990) phase I-III descriptions refer to ventral beveling, the formation of the ventral rampart, and the presence or absence of ossific nodules in phases II and III. Hartnett omits ventral beveling and the ventral rampart from her descriptions, but does mention ossific nodules in phase II and the possible presence of, "a rounded buildup of bone in the gap between the upper and lower extremities" in phase III (Hartnett 2010a:1151). Brooks and Suchey (1990) stated that pubic symphyses in phase IV should be fine-grained, while those in Hartnett's (2010a) phase IV are becoming somewhat porous.

By phase V in all three methods, the development of an oval outline or rim around the symphyseal face is complete and may be starting to erode (Table 2.1) (Berg 2008; Brooks and Suchey 1990; Hartnett 2010a). In this phase the symphyseal face is slightly depressed in relation to the rim, and Hartnett (2010a) and Berg (2008) both mention that the face is becoming porous and that the bone may feel somewhat light weight. Phase VI in all three methods is characterized by breakdown of the rim and marked porosity. Brooks and Suchey (1990) and Hartnett discuss the buildup of bone on the ventral surface of the pubis, while Berg says that the bone in this area may have a striated quality. Brooks and Suchey use the term "crenellations" to describe what Hartnett calls irregularity of the rim. Berg's and Hartnett's new phase VII is distinguished from phase

VI by extensive porosity, breakdown of the symphyseal face and rim, and very light weight due to loss of bone, i.e., osteopenia or osteoporosis.

Berg (2008) does not mention the pubic tubercle in his phase descriptions, while Brooks and Suchey (1990:233) state that in phase VI it, “may appear as a separate bony knob,” and Hartnett (2010a:1151) finds that it is “elaborate and proliferative” in phase VII (Table 2.1). Berg states that dorsal lipping is usually moderate in phase VII, although he describes this characteristic as “highly variable.” Brooks and Suchey mention dorsal lipping in phases IV and V, where it may be slight or moderate, respectively. They do not include this characteristic in their description of phase VI, and it is not present before phase IV. Hartnett says that slight dorsal lipping may be present in phase III and by phase IV there is slight lipping. She does not mention lipping in phase V, but notes that lipping is definitely present in phase VI and in VII it becomes pronounced.

Berg (2008) emphasized the presence and relative severity of porosity on the symphyseal face and pubic bone in his descriptions of phases V-VII (Table 2.1). In his phase V porosity affects less than 15% of the symphyseal face and should not affect the pubic bone itself. Berg’s criteria for differentiating phases V and VI are very strict: if the surface of a symphysis is more than 15% porous or if there is more than extremely mild osteopenia/osteoporosis, then an individual must be scored as greater than a phase V. Therefore, if an observer notes that an individual has at least mild osteopenia/ osteoporosis, then they would be required to categorize the individual as a phase VI or VII even if they might otherwise have classified the individual as a phase IV or V. Berg reminds readers that bone loss in females begins around the age of 35 years and that approximately 50% of women over 60 years old have significant bone loss, so it seems that even middle-aged women with mild osteopenia/osteoporosis would fall into phase VI. Berg's phase VI is typified by less than or approximately 50% of the face covered in, "porosities or small channel-like structures—coalescences of smaller porosities into oblong pores/channels" (Berg 2008:574). In phase VII most or all of the symphyseal face is porous and macroporous and the face appears flattened due to rim erosion.

Hartnett (2010a) highlights the quality and texture of the dorsal and ventral surfaces of the pubic bone in her phase descriptions. Individuals in phases I-III have smooth, firm, heavy, and dense bone (Table 2.1). Beginning in phase IV the surface of the bone becomes rough, with a texture similar to sand paper. Hartnett uses the words "rough" and "coarse" to describe this sandpaper-like condition, and defines "irregular" as having small bony projections (Hartnett 2010a:1148-1149). She describes the texture in phase IV as "roughened and becoming coarse," phase V as "roughened and irregular" on the ventral surface and "coarse and irregular" on the dorsal surface, phase VI as "rough and coarse" on the dorsal surface, and phase VII as "roughened and elaborate" on the ventral surface and "roughened" on the dorsal surface (Hartnett 2010a:1151). This range of descriptors does not seem to effectively differentiate the texture of the bone from one phase to another. However, Merritt's (2014:701) validation study found that, "Hartnett's revisions of the physical and textural descriptions of each phase were helpful in clarifying differences among phases, especially with older individuals."

Table 2.1. Suchey-Brooks (1990), Hartnett (2010a), and Berg (2008) phase descriptions.

Phase	Method	Description
I	Suchey-Brooks (1990) and Berg (2008)	Symphyseal face has a billowing surface composed of ridges and furrows which includes the pubic tubercle. The horizontal ridges are well-marked. Ventral beveling may be commencing. Although ossific nodules may occur on the upper extremity, a key feature of this phase is the lack of delimitation for either extremity (upper or lower).
	Hartnett (2010a)	A clear ridge and furrow system extends from the pubic tubercle onto the inferior ramus. Ridges and furrows are deep and well-defined and do not look worn down. There is no dorsal lipping. Bone is of excellent quality and is firm, heavy, dense, and smooth on the ventral and dorsal body. There is no rim formation. The dorsal plateau is not formed. The ridges and furrows extend to the dorsal edge.
II	Suchey-Brooks (1990) and Berg (2008)	Symphyseal face may still show ridge development. Lower and upper extremities show early stages of delimitation, with or without ossific nodules. Ventral rampart may begin formation as extension from either or both extremities.
	Hartnett (2010a)	The rim is in the process of forming, but mainly consists of a flattening of the ridges on the dorsal aspect of the face and ossific nodules present along the ventral border. Ridges and furrows are still present. The ridges and furrows may appear worn down or flattened, especially on the dorsal aspect of the face. The furrows are becoming shallow. The upper and lower rim edges are not formed. There is no dorsal lipping. The bone quality is very good and the bone is firm, heavy, dense, and smooth on the ventral and dorsal body, with little porosity. The pubic tubercle may appear separate from the face.
III	Suchey-Brooks (1990) and Berg (2008)	Symphyseal face shows lower extremity and ventral rampart in process of completion. Fusing ossific nodules may form upper extremity and extend along ventral border. Symphyseal face may either be smooth or retain distinct ridges. Dorsal plateau is complete. No lipping of symphyseal dorsal margin or bony ligamentous outgrowths.
	Hartnett (2010a)	The lower rim is complete on the dorsal side of the face, and is complete until it ends approximately halfway up the ventral face leaving a medium to fairly large gap between the lower and upper extremities on the ventral face. This enlarged ''V'' is longer on the dorsal side than the ventral side. Some ridges and shallow furrows are still visible, but appear worn down. In some cases, the face is becoming slightly porous. The rim is forming both on the dorsal aspect of the face and the upper and lower extremities. In some cases, there is a rounded buildup of bone in the gap between the upper and lower extremities above the enlarged ''V.'' Bone quality is good; the bone is firm, heavy, dense, and has little porosity. The dorsal surface of the body is smooth, and there are small bony projections near the medial aspect of the obturator foramen. The ventral aspect of the body is not elaborate. Very slight to no dorsal lipping. Quality of bone and rim completion are important deciding factors. Variant: In some cases, a deep line or epiphysis is visible on the ventral aspect parallel to and adjacent to the face (males only).

Table 2.1. Suchey-Brooks (1990), Hartnett (2010a), and Berg (2008) phase descriptions.		
Phase	**Method**	**Description**
IV	Suchey-Brooks (1990) and Berg (2008)	Symphyseal face is generally fine-grained, although remnants of ridge and furrow system may remain. Oval outline usually complete at this stage, though a hiatus may occur in upper aspect of ventral circumference. Pubic tubercle is fully separated from the symphyseal face through definition of upper extremity. Symphyseal face may have a distinct rim. Ventrally, bony ligamentous outgrowths may occur in inferior portion of pubic bone adjacent to symphyseal face. Slight lipping may appear on dorsal border.
	Hartnett (2010a)	In most cases, the rim is complete at this stage, but may have a small ventral hiatus on the superior and ventral aspect of the rim. The face is flattened and not depressed. Remnants of ridges and furrows may be visible on the face, especially on the lower half. The quality of bone is good, but the face is beginning to appear more porous. The dorsal and ventral surfaces of the body are roughened and becoming coarse. There is slight dorsal lipping. In females with parturition pits, dorsal lipping can be more pronounced. The ventral arc may be large and elaborate in females.
V	Suchey-Brooks (1990)	Slight depression of the face relative to a completed rim. Moderate lipping is usually found on the dorsal border with prominent ligamentous outgrowths on the ventral border. Little or no rim erosion, though breakdown possible on superior aspect of ventral border.
	Hartnett (2010a)	The face is becoming more porous and is depressed, but maintains an oval shape. The face is not irregularly-shaped or erratic. The rim is complete at this stage. In general, the rim is not irregular. Ridges and furrows are absent on the face. There may be some breakdown of the rim on the ventral border, which appears as irregular bone (not rounded/solid). The ventral surface of the body is roughened and irregular, with some bony excrescences. The dorsal surface of the body is coarse and irregular. Projections are present on the medial aspect of the obturator foramen. Bone quality is good to fair; it is losing density and is not smooth. The bone is moderately light in weight. In females the ventral arc is prominent.
	Berg (2008)	The rim is complete at this stage, but the symphyseal face may show a slight depression as it begins to erode. The pubic tubercle is separated from the face. The quality of bone on the articular surface is still good and very compact. In a few cases, a slight amount of porosity may be present, but it usually affects less than 15% of the symphyseal face. Only extremely mild signs of osteoporosity ⁄ osteopenia are present (if any) and the ventral aspect of the symphysis is typically not porous. Decision-making traits are: (i) if the articular surface still has majority of compact bone with less than 15% porosity anywhere on surface, and (ii) osteoporosity/osteopenia is absent or extremely mild, score as a phase V. If either of these two traits is observed greater than specified, then score as greater than a phase V.
VI	Suchey-Brooks (1990)	Symphyseal face shows ongoing depression as rim erodes. Ventral ligamentous attachments are marked. Pubic tubercle may appear as a separate bony knob. Face may be pitted or porous, giving an appearance of disfigurement as the ongoing process of erratic ossification proceeds. Crenellations may occur, with the shape of the face often irregular.

Table 2.1. Suchey-Brooks (1990), Hartnett (2010a), and Berg (2008) phase descriptions.		
Phase	**Method**	**Description**
VI	Hartnett (2010a)	The face is losing its oval shape and is becoming irregular. The rim is complete, but breaking down, especially on the ventral border. The rim and face are irregular, porous, and macroporous. Bone quality is fair, and the bone is lighter and more porous, even with bony buildup on the ventral body surface. The rim is eroding. The dorsal surface of the bone is rough and coarse. There are no ridges and furrows. Dorsal lipping is present. Projections are present at the medial aspect of the obturator foramen. Bone weight is a major deciding factor between phases VI and VII.
	Berg (2008)	The symphyseal face is usually depressed and the rim begins to erode, beginning with the superior ventral aspect. The quality of bone on the articular surface is breaking down, no longer retaining the smooth, compact surface. The symphyseal face is eroded, in the form of either porosities or small channel-like structures—coalescences of smaller porosities into oblong pores/channels. Osteoporosis is mild to moderate in this phase. Lipping of the articular surfaces can be present. Decision-making traits are: (i) less than 50% of the symphyseal surface is porous, and (ii) lipping is mild to moderate than it is scored as a phase VI. If the symphyseal face appears to be borderline (40-60% of face is porous but still a fair amount of compact bone), then osteoporosity/ osteopenia should be used as the deciding feature. If this trait is moderate to severe, then it is scored as a phase VII. The weight of the bone should be the primary indicator, though other indications of osteoporosity/osteopenia can be found on the ventral aspect of the pubis where porosity may be present and the bone may have a striated quality.
VII	Hartnett (2010a)	The face and rim are very irregular in shape and are losing integrity. The rim is complete but is eroding and breaking down, especially on the ventral border. There are no ridges and furrows. The face is porous and macroporous. Dorsal lipping is pronounced. Bone quality is poor, and the bone is very light and brittle. Bone weight is an important deciding factor. The dorsal surface of the bone is roughened. The ventral surface of the body is roughened and elaborate. Projections are present at the medial wall of the obturator foramen. The pubic tubercle is elaborate and proliferative. Bone weight is a major deciding factor between phases VI and VII.
	Berg (2008)	The symphyseal face is extremely porous and eroded with >50% of its surface. Osteoporosity/osteopenia is present and is typically moderate to severe in nature (often, the bone is light in weight). The symphyseal face appears to be relatively flat, since the rim is highly eroded and is losing definition. The ventral surface of the symphysis is typically scarred or has striated bone with ligamentous outgrowths, occurring typically near the obturator foramen. Lipping of the articular surfaces is often moderate, but may be mild or severe. This character is highly variable.

CHAPTER 3: METHODS

Materials

The study sample is composed of adult individuals from the William M. Bass Donated Skeletal Collection at the University of Tennessee, Knoxville, TN. The Bass Collection is composed of modern North American individuals with dates of death ranging from approximately 1981 to the present (UTK 2014). Individuals from the Bass Collection constitute an appropriately modern sample on which to test the new seven-phase pubic symphysis methods proposed by Hartnett (2010a) and Berg (2008). In addition, neither Brooks and Suchey's (1990) nor Hartnett's methods were developed using the Bass Collection. Berg (2004) examined 104 females from the Bass Collection during his development of a seven-phase technique. The present author selected females donated between 2006 and 2011 so that the study sample did not overlap Berg's reference sample.

The present study examined only White individuals due to the paucity of other ancestral groups in the Bass Collection (UTK 2014). Minority ancestral groups compose less than 25% of the collection, and their inclusion in this study sample might have confounded statistical analyses due to small sample sizes and differing genetic and environmental factors that influence the aging process (Katz and Suchey 1989; Schmitt *et al.* 2002). Although around two-thirds of the individuals in the Bass Collection are male, the sample for the present study was selected with the aim of including approximately equal numbers of males and females. The study sample included 384 individuals, 55.5% of whom were male and 44.5% of whom were female. Adults in the Bass Collection are predominantly over 40 years old at death, so the sample's age distribution reflects the collection's age distribution (Figures 3.1 and 3.2) (UTK 2014). However, due to the focus of the present study on the validation of a seventh phase for the pubic symphysis age estimation method, the collection's skewed age-at-death profile was beneficial rather than detrimental. The 213 males included in the sample ranged in age from 26 to 89 years at death, while the 171 females ranged in age from 29 to 97 years (Table 3.1).

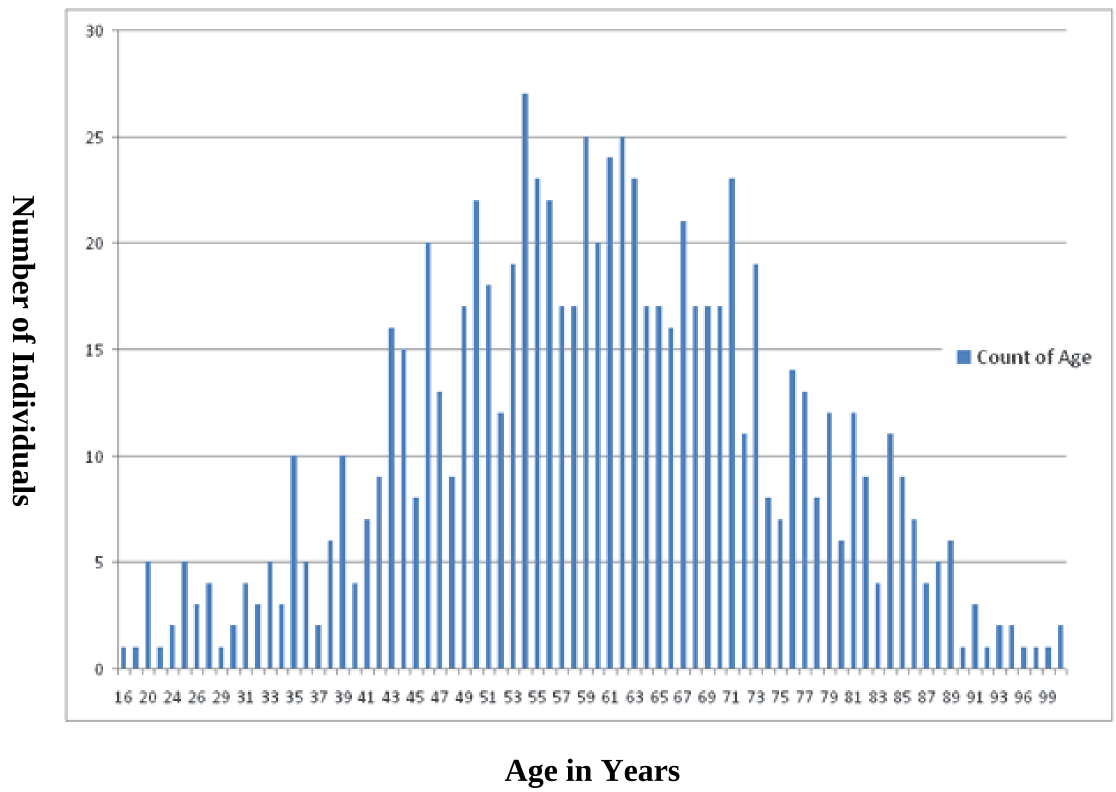

Figure 3.1. Age distribution of the William M. Bass Donated Skeletal Collection (UTK 2014).

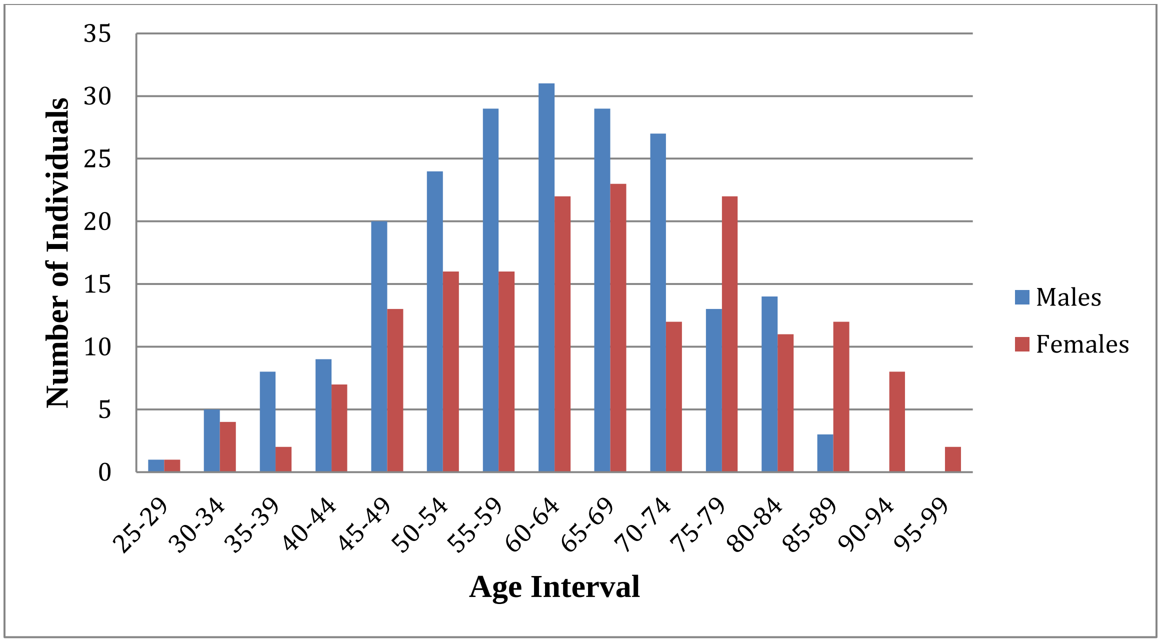

Figure 3.2. Age distribution of the sample used in the present study.

Table 3.1. Descriptive statistics of the recorded ages of the individuals in the sample.

	n =	Mean	Median	SD	100% Interval
Males	213	60.88	62	12.77	26-89
Females	171	65.33	65	15.34	29-97
Total	384	62.86	63	14.13	26-97

Some individuals in the Bass Collection initially considered for inclusion in the study sample were ruled out for various reasons. These included individuals with antemortem pathological conditions or extensive postmortem breakage that affected the integrity of the symphyseal face (Warmlander and Sholts 2010). Individuals with bilateral sacroiliac fusion could not be included in the study sample, because the pubic symphyses were not visible. In cases where unilateral sacroiliac fusion was present, the unfused innominate was examined. Similarly, individuals with bilateral hip replacements were excluded, and in individuals with unilateral hip replacements the unaffected innominate was examined. Exclusion of innominates with unilateral sacroiliac fusion or hip replacements was necessary due to the effect of the additional element (sacrum or hip replacement) on the mass of the bone, which was a factor in both Hartnett's (2010a) and Berg's (2008) phase descriptions. If an individual lacked antemortem pathological changes or postmortem breakage on both innominates, then the selection of a right or left innominate was random and not recorded due to the statistically insignificant effects of asymmetry on the assignment of an individual to a certain phase (Hens *et al.* 2008; Overbury *et al.* 2009; Sharma *et al.* 2008; Warmlander and Sholts 2010).

Examination of the Study Sample

Assessment of the study sample was conducted while referring to the phase descriptions from each aging system but without the photographs and drawings. The pubic symphysis casts made by Diane France were utilized in conjunction with the Suchey-Brooks method (Brooks and Suchey 1990; France 2012).

Due to space constraints the sample was analyzed in groups of 10-14 individuals. Each group was assessed first with the Suchey-Brooks (1990) method, then with the Hartnett (2010a) method, and finally the females were assessed using the Berg (2008) method. Individuals' phase assignments using methods other than the one under consideration were made unavailable. Innominates were placed in opaque paper bags labeled with the individual's sex and catalog number so that all areas of the bone except the pubis were obscured. This precaution was taken so that the auricular surface and acetabulum were not visible to the observer and therefore could not bias pubic symphysis phase assignments (Calce 2012; Lovejoy *et al.* 1985a; Rouge-Maillart *et al.* 2004). Placement of the innominates inside paper bags had the added benefit of maintaining consistency with the Suchey-Brooks and Hartnett methods, which were developed using pubes that were removed at autopsy and thus could not be biased by visual clues from any other portion of the skeleton (Dror *et al.* 2006; Dror and Rosenthal 2008; Nakhaeizadeh *et al.* 2014).

Twenty male individuals and twenty female individuals, who were intended to correspond to approximately 10% of the author's final study sample, were chosen at random for examination by a second observer to evaluate inter-observer error. Due to time constraints and an unequal number of males and females in the study sample, the inter-observer sample represents 9.4% of the males and 11.7% of the females in the study sample. The author gave the second observer a brief explanation of the Hartnett and Berg methods and showed her exemplars of each Hartnett and Berg phase. The second observer, a colleague of the author's, was allowed to refer to the article—Brooks and Suchey (1990), Hartnett (2010a), or Berg (2008)—that described the method she was using to assess the sample. The second observer otherwise followed the same methods as the author and was blind to the author's phase assignments. After analyzing the 384 individuals in the study sample the author reevaluated 58 randomly selected individuals to assess intra-observer error. The intra-observer sample consisted of 32 males and 26 females who made up 15.1% of the study sample. The author was blind to previous phase assignments. A weighted Kappa statistic was used to assess the degree of inter- and intra-observer error (Landis and Koch 1977; Merritt 2014).

Descriptive statistics were calculated for each method including the mean, standard deviation, and 100% interval of the recorded ages-at-death of both sexes for each phase (Tables 4.1-4.3). Statistical analyses exist for testing the significance of the observed difference between the means calculated for two separate samples. However, as Konigsberg *et al.* (2008:542) noted, these differences merely reflect the discrepancies between the age structures of the study sample, i.e. the sample being analyzed by observers who did not design the method, and the reference sample that the creators of the method used to formulate and test it. Therefore, traditional statistical analyses that calculate the significance of the difference between means would be inappropriate.

Statistical Analyses

Respondents to Garvin and Passalaqua's (2012) survey employed various statistics to generate age estimates, so the percentage of individuals whose ages-at-death were estimated "correctly" by each method can be defined in several ways. The author calculated the percentages of correct estimates using ± one and ± two standard deviations from individuals' assigned phase means. The author also calculated the percentages of individuals' recorded ages that fell within the age intervals provided in the three methods studied. However, the age intervals were not consistently reported; Brooks and Suchey (1990) provided 95% age intervals, Hartnett (2010a) provided 100% age intervals, and Berg (2008) provided phase means and standard deviations but no age intervals.

Therefore, Brooks and Suchey's and Hartnett's percentages of correct estimates for males are compared using their respective 95% and 100% age intervals as well as using ± one and ± two standard deviations from the phase means. Percentages of correct estimates for females are compared using ± one and ± two standard deviations from the phase means provided by Brooks and Suchey, Hartnett, and Berg. All statistical comparisons between Berg (2008) and the present study employ the statistics Berg computed for his sample at the Bass Collection.

Lovejoy *et al.* (1985a, b) employed two new formulae that use published phase means and individuals' recorded ages-at-death to check the reliability of age estimation methods. Both formulae calculate the differences between individuals' recorded ages-at-death and their "estimated ages" (Lovejoy *et al.* 1985a). Authors who employ a single method to estimate age use the published mean age-at-death of the phase to which an individual is assigned as the "estimated age" for their calculations (Hens *et al.* 2008; Merritt 2014; Schmitt 2004). The first formula calculates inaccuracy by computing the average *absolute* distance of individuals' recorded ages-at-death away from their phase means ($\Sigma|\text{phase mean} - \text{recorded age}|/n$) (Lovejoy *et al.* 1985a, b). The formula for inaccuracy uses an absolute value, so it does not take into account whether an individual's recorded age-at-death was greater than or less than the phase mean (Hens *et al.* 2008; Lovejoy *et al.* 1985a, b; Merritt 2014; Murray and Murray 1991; Schmitt 2004). The formula that calculates bias determines the average difference between individuals' recorded ages-at-death and their phase means ($\Sigma[\text{phase mean} - \text{recorded age}]/n$) (Lovejoy *et al.* 1985a, b). By calculating the average distance of individuals' recorded ages-at-death above or below phase means, the formula for bias assesses the tendency of an age estimation method to over- or underestimate individuals' ages-at-death (Hens *et al.* 2008; Lovejoy *et al.* 1985a; Merritt 2014; Murray and Murray 1991; Schmitt 2004).

Inaccuracy and bias scores were calculated for each sex based on phase and age interval using Brooks and Suchey's (1990), Hartnett's (2010a), and Berg's (2008) methods. Paired t-tests were conducted to evaluate the statistical significance of the differences between the inaccuracy and bias scores for different methods based on sex and age interval (Kimmerle *et al.* 2008; Merritt 2014). All statistical analyses were performed with Microsoft Office *Excel*, 2010.

CHAPTER 4: RESULTS

Descriptive Statistics

The author scored all individuals as Suchey-Brooks (1990) phases IV-VI, with greater than 30 males and females in each phase except for females in phase IV, which consisted of only nine individuals (Table 4.1). The lack of individuals assigned to phases I-III using the Suchey-Brooks, Hartnett (2010a), and Berg (2008) age-at-death estimation methods is likely due to the age structure of the study sample, which contains only two individuals aged 26-29 years at death and nineteen individuals aged 30-39 years (Figure 4.1). Most females (60.2%) were assigned to Suchey-Brooks phase VI, and many males (48.8%) were assigned to phase V. The phase means for males and females in the present study were all greater than the published phase means by 5.47 years (females phase IV) to 14.36 years (females phase V) (Brooks and Suchey 1990). Standard deviations published by Brooks and Suchey (1990) for phases IV-VI range from 9.2-12.4 years in males and 10.9-14.6 years in females. Standard deviations for the present study range from 9.90-10.95 years in males and 11.20-14.53 years in females. The upper limits of the 100% age intervals in the present study were greater than the upper limits of the published 95% intervals in all phases except for females in phase IV, which may be anomalous due to its small sample size. The lower limits of the 100% intervals in the present study were greater than the lower limits of the published 95% intervals in all phases except for females in phase VI, whose 100% age interval in the present study spans 60 years. There was substantial overlap between the 100% age intervals and the middle 50% of females in phases V and VI (Figure 4.1). The discrepancy in age intervals and phase means between the figures published by Brooks and Suchey (1990) and those in the present study is likely a manifestation of the differing age structures of the reference and study samples. The large standard deviations and wide age intervals associated with each phase reflect the variability of the aging process, which makes adult age estimation difficult even for experienced observers (Algee-Hewitt 2013; Hoppa 2000; Katz and Suchey 1989; Konigsberg *et al*. 2008; Schmitt *et al.* 2002).

Table 4.1. Descriptive statistics for males and females using the Suchey-Brooks (1990) method.

		Brooks and Suchey (1990)				Present Study			
	Phase	**n =**	**Mean**	**SD**	**95% Interval**	**n =**	**Mean**	**SD**	**100% Interval**
Males	IV	171	35.2	9.4	23-57	32	47.09	10.95	26-70
	V	134	45.6	10.4	27-66	103	58.64	10.35	31-82
	VI	203	61.2	12.2	34-86	78	69.50	9.90	44-89
Females	IV	39	38.2	10.9	26-70	9	43.67	11.20	31-61
	V	44	48.1	14.6	25-83	59	62.46	14.53	29-89
	VI	51	60.0	12.4	42-87	103	68.86	14.27	37-97

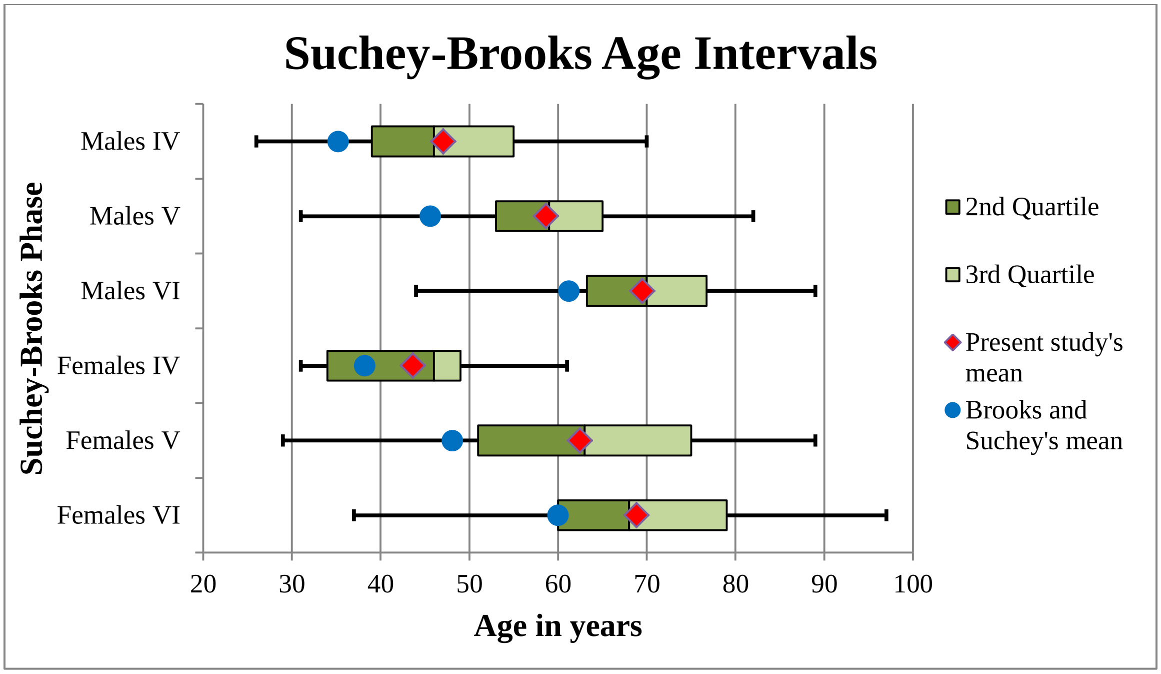

Figure 4.1. Box and whisker plot of the means and 100% age intervals calculated using the sampled individuals' Suchey-Brooks phase assignments. Red diamonds indicate the phase means calculated by the author, while blue circles denote the phase means presented by Brooks and Suchey (1990).

The author scored all females and all but one male as Hartnett (2010a) phases IV-VII. The single male in phase III limits statistical analyses of that phase. The sample sizes for males in phases IV-VI are all greater than 35, and the sample sizes for females in phases V-VII are all greater than or equal to 40 (Table 4.2). There are sixteen males in phase VII and twelve females in phase IV. Most males (51.2%) were assigned to phase V, while many females (43.3%) were assigned to phase VI. Phase means in the present study are greater than published phase means for males in phases IV-VI and females in phases IV and V. Standard deviations presented by Hartnett for phases IV-VII range from 8.06-9.33 years in males and 3.94-7.41 years in females. Standard deviations for the present study range from 8.36-12.63 years in males and 11.42-13.86 years in females. Standard deviations in the present study are greater than published standard deviations for all phases except males in phase VII. Standard deviations for females in phases IV and V in the present study are over twice and three times the size of published standard deviations, respectively. Upper limits of the 100% age intervals in the present study are greater than the upper limits of the published 100% intervals in males and females in phases IV-VI, while the upper limits of both sexes in phase VII are constrained by the recorded ages-at-death of some of the oldest individuals in the study sample. Lower limits of the 100% age intervals in the present study are all less than the lower limits of the published 100% intervals. The 100% age interval for males in phase VI completely overlapped the 100% age interval for males in phase VII (Figure 4.2). The means for these phases are only 2.61 years apart, which suggests that a phase VII for males may not be useful due to the minor differences in the age structures of phases VI and VII. Disparities in phase means between the reference and study samples can be explained by differing sample age structures, whereas the dissimilarities in standard deviations and 100% age intervals could be due to a variety of factors including observers' experience with the method (Algee-Hewitt 2013).

Table 4.2. Descriptive statistics for males and females using the Hartnett (2010a) method.

		Hartnett (2010a)				Present Study			
	Phase	**n =**	**Mean**	**SD**	**100% Interval**	**n =**	**Mean**	**SD**	**100% Interval**
Males	III	36	29.53	6.63	21-44	1	39.00	---	---
	IV	69	42.54	8.80	27-61	39	50.11	12.63	26-73
	V	90	53.87	8.42	37-72	109	58.94	10.18	33-82
	VI	34	63.76	8.06	51-83	49	70.14	9.87	48-89
	VII	96	77.00	9.33	58-97	16	72.75	8.36	54-88
Females	IV	35	43.26	6.12	33-58	12	47.25	13.86	31-81
	V	32	51.47	3.94	44-60	45	57.89	13.52	29-89
	VI	35	72.34	7.36	56-86	74	66.65	13.38	37-94
	VII	56	82.54	7.41	62-99	40	76.68	11.42	56-97

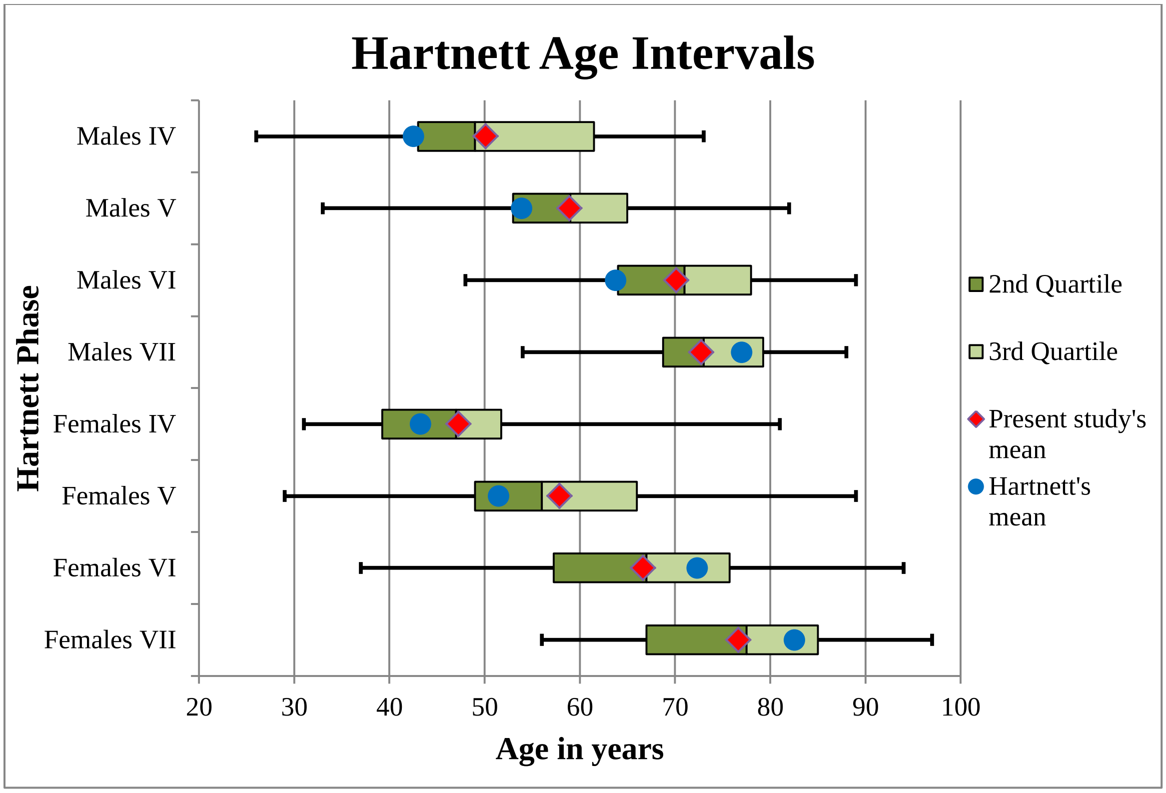

Figure 4.2. Box and whisker plot of the means and 100% age intervals calculated using the sampled individuals' Hartnett (2010a) phase assignments. Red diamonds indicate the phase means calculated by the author while blue circles denote the phase means presented by Hartnett. The male in phase III is not shown.

The author scored all females as Berg (2008) phases IV-VII, which is expected given that Berg did not modify Brooks and Suchey's (1990) phase I-III descriptions, and no individuals were assigned to those phases when the Suchey-Brooks method was tested in the present study. The study sample sizes were greater than or equal to 20 for Berg phases V-VII, although only four individuals were assigned to phase IV (Table 4.3). Inadequate sample sizes for phase IV in both the reference and study samples may skew statistical analyses for that phase. Most females (59.6%) were assigned to phase VII. Phase means in the present study are greater than published means in phases IV and V.

There was nearly complete overlap between the 100% age intervals and middle 50% of individuals in phases V and VI (Figure 4.3). In addition, the mean for phase V is 3.56 years greater than the phase VI mean. Standard deviations published by Berg (2008) for phases IV-VII range from 3.8-10.9 years, while standard deviations for the present study range from 9.29-14.27 years. Standard deviations in the present study are greater than published standard deviations for all phases. Standard deviations for phases IV and V in the present study are over twice the size of published standard deviations. Differences in reference and study sample age structures cannot account for the inconsistencies seen in the phase means and standard deviations for this method, because the two samples were drawn from the same skeletal collection and have comparable age profiles. Therefore, another factor such as observer experience may be the cause of these discrepancies (Algee-Hewitt 2013).

Table 4.3. Descriptive statistics for females using the Berg (2008) method.

		Berg (2008) Bass Collection			Present Study			
	Phase	n =	Mean	SD	n =	Mean	SD	100% Interval
Females	IV	6	35.5	3.8	4	46.50	9.29	31-61
	V	18	49.7	5.8	20	59.60	13.65	31-82
	VI	27	64.2	9.0	45	56.04	14.03	29-82
	VII	50	74.2	10.9	102	71.28	14.27	42-97

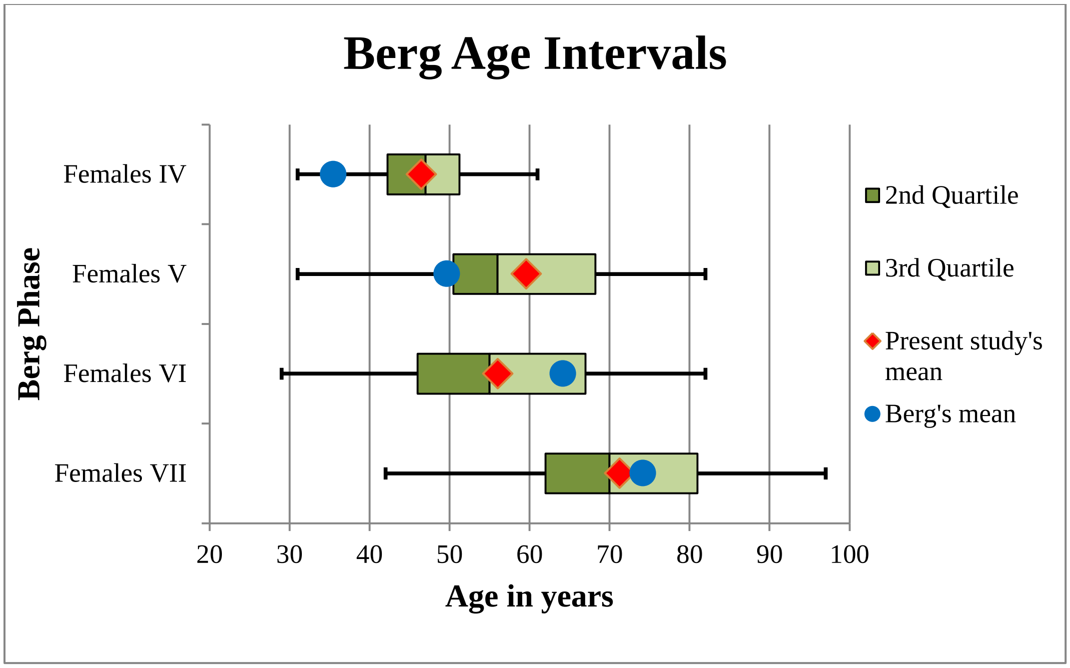

Figure 4.3. Box and whisker plot of the means and 100% age intervals calculated using the sampled individuals' Berg(2008) phase assignments. Red diamonds indicate the phase means calculated by the author while blue circles denote the phase means presented by Berg.

Correctness

"Correctness" was defined as whether or not an individual's recorded age-at-death fell within a distinct age interval for their assigned phase, including the published 95% or 100% interval, ± one standard deviation from the phase mean, or ± two standard deviations from the phase mean. Using Brooks and Suchey's (1990) 95% age intervals, 87.8% of males' and 96.5% of females' ages-at-death were estimated correctly (Table 4.4). Rates of correct classifications for males were 47.9% using an age interval of ± one standard deviation from the phase means and 84.5% with ± two standard deviations from the phase means. The percentages of females with correct estimates were similar: 50.3% were within ± one standard deviation of the phase means, and 82.5% were within ± two standard deviations of the phase means. In phase IV for males and phases IV-VI for females, the published 95% intervals were more accurate than ± two standard deviations from the phase means, while the two age intervals performed equally well for males in phases V and VI.

Table 4.4. Percentages of correct classifications using the Suchey-Brooks (1990) method.

	Phase	n =	Within published 95% interval	Within ± 1SD of published mean	Within ± 2SD of published mean
Total		384	91.7%	49.0%	83.6%
Males	Total	213	87.8%	47.9%	84.5%
	IV	32	84.4%	37.5%	71.9%
	V	103	79.6%	40.8%	79.6%
	VI	78	96.2%	61.5%	96.2%
Females	Total	171	96.5%	50.3%	82.5%
	IV	9	100.0%	77.8%	88.9%
	V	59	93.2%	44.1%	81.4%
	VI	103	86.4%	51.5%	82.5%

The percentages of correct age estimates for males were similar using Hartnett's (2010a) 100% age intervals and Brooks and Suchey's (1990) 95% intervals, but Hartnett was less accurate than Suchey-Brooks for females (Tables 4.4 and 4.5). The overall percentages of correct classifications were 87.8% for males and 69.6% for females using Hartnett's published 100% intervals (Table 4.5). On average, the age intervals consisting of ± two standard deviations from the phase means correctly estimated the ages-at-death of 85.0% of males and 68.4% of females, which are slightly less than the percentages of correct classifications using the 100% intervals. The age intervals consisting of ± one standard deviation from the phase means yielded correct age estimates for 53.1% of males and 39.8% for females. Therefore, when using the Hartnett method, the highest accuracy rates will be obtained using the published 100% age intervals.

Table 4.5. Percentages of correct classifications using the Hartnett (2010a) method.

	Phase	n =	Within published 100% interval	Within ± 1SD of published mean	Within ± 2SD of published mean
Total		384	79.7%	47.1%	77.6%
Males	Total	213	87.8%	53.1%	85.0%
	III	1	100.0%	0.0%	100.0%
	IV	38	71.1%	44.7%	73.7%
	V	109	90.8%	55.0%	87.2%
	VI	49	91.8%	44.9%	85.7%
	VII	16	93.8%	87.5%	93.8%
Females	Total	171	69.6%	39.8%	68.4%
	IV	12	66.7%	41.7%	83.3%
	V	45	53.3%	28.9%	48.9%
	VI	74	71.6%	44.6%	73.0%
	VII	40	87.5%	42.5%	77.5%

The Berg (2008) method for estimating the ages-at-death of adult females was less accurate than the Suchey-Brooks (1990) method but more accurate than the Hartnett (2010a) method in the present study. Overall, 78.4% of females were within ± two standard deviations of the Berg method's phase means (Table 4.6). Applying the same criterion, 82.5% of females were classified correctly with the Suchey-Brooks method and 68.4% were classified correctly with the Hartnett method (Tables 4.4 and 4.5). The age intervals consisting of ± one standard deviation from the phase means yielded correct age estimates for 43.3% of females using the Berg method, while Suchey-Brooks and Hartnett generated 50.3% and 39.8% correct estimates, respectively (Tables 4.4-4.6).

Table 4.6. Percentages of correct classifications using the Berg (2008) method.

	Phase	n =	Within ±1SD of published mean	Within ±2SD of published mean
Females	Total	171	43.3%	78.4%
	VI	4	0.0%	25.0%
	V	20	35.0%	50.0%
	VI	45	28.9%	71.1%
	VII	102	52.9%	89.2%

A comparison of the percentages of each method's correct classifications for various age intervals shows which method(s) are best for age-at-death estimation of older or younger adults. Table 4.7 illustrates these percentages for males and females using ± one standard deviation and ± two standard deviations from individuals' assigned phase means—the only published statistics that are available in all three methods—in ten year age intervals. Males aged 26-39 years at death have their ages-at-death more accurately estimated using the Suchey-Brooks (1990) method, while males aged 40-69 years have better estimates using the Hartnett (2010a) method. Percentages of correct estimates are variable for males aged 70-89 years at death. Males aged 70-79 years at death have very similar percentages of correct estimates using both methods. Using ± one standard deviation from phase means, males aged 80-89 years have more accurate age estimates using the Hartnett method, but when using ± two standard deviations, the same age interval yields better age estimates using the Suchey-Brooks method.

Table 4.7. Percentages of classifications within one or two standard deviations of the assigned phase means per ten year age interval for the Suchey-Brooks (1990), Hartnett (2010a), and Berg (2008) methods.

Age Interval	SD	n =	Suchey-Brooks Males	Hartnett Males	n =	Suchey-Brooks Females	Hartnett Females	Berg Females
26-39	±1	14	85.71%	35.71%	7	57.14%	0.00%	0.00%
	±2		100.00%	85.71%		100.00%	42.86%	14.29%
40-49	±1	29	62.07%	79.31%	20	70.00%	40.00%	10.00%
	±2		100.00%	100.00%		100.00%	65.00%	25.00%
50-59	±1	53	67.92%	79.25%	32	96.88%	31.25%	34.38%
	±2		90.57%	98.11%		100.00%	62.50%	84.38%
60-69	±1	60	36.67%	43.33%	45	73.33%	35.56%	57.78%
	±2		83.33%	88.33%		97.78%	62.22%	88.89%
70-79	±1	40	35.00%	32.50%	34	11.76%	73.53%	73.53%
	±2		75.00%	77.50%		94.12%	85.29%	94.12%
80-89	±1	17	0.00%	23.53%	23	0.00%	39.13%	43.48%
	±2		52.94%	23.53%		26.09%	73.91%	86.96%
90-97	±1	0			10	0.00%	0.00%	0.00%
	±2					0.00%	70.00%	90.00%

The Suchey-Brooks method was the most accurate for estimating the ages-at-death of females aged 26-69 years (Table 4.7). The Berg (2008) and Hartnett (2010a) methods both estimated 73.5% of females' ages-at-death correctly for individuals aged 70-79 years using ± one standard deviation from the phase means, while the Suchey-Brooks and Berg methods both estimated 94.1% of the same individuals' ages correctly using ± two standard deviations from the phase means. The Berg method was the most accurate for estimating the ages-at-death of females aged 80-97 years, although none of the three methods correctly estimated the ages of the ten females aged 90-97 years using ± one standard deviation from the phase means.

Inaccuracy and Bias

By calculating the average inaccuracy or bias scores for males and females in each phase of each method, it is possible to see which phases are most inaccurate and whether phase means tend to over- or underestimate age-at-death. Inaccuracy and bias scores that approach zero indicate that a phase or method accurately predicts individuals' ages-at-death using published phase means. Negative bias values indicate that a phase or method underestimates individuals' ages-at-death, while positive values reveal a tendency to overestimate age-at-death.

Of the three methods tested, the Suchey-Brooks (1990) phases yielded some of the highest mean inaccuracy scores, which ranged from 10.09 years (females phase IV) to 16.52 years in the present study (females phase V) (Table 4.8). Hartnett's (2010a) phases were some of the least inaccurate, with inaccuracy values ranging from 7.38 years (males phase VII) to 11.93 years (males phase IV) (Table 4.9). Inaccuracy scores for Berg's (2008) phases ranged from 11.12 years (females phase VII) to 13.99 years (females phase VI) (Table 4.10). Suchey-Brooks phase means consistently underestimated the ages-at-death of individuals in the study sample by 5.47 years (females phase IV) to 14.36 years (females phase V) (Table 4.8). Hartnett phases III-VI for males and phases IV and V for females underestimated individuals' ages-at-death by 3.99 years (females phase IV) to 9.47 years (males phase III) (Table 4.9). However, males in Hartnett phase VII and females in phases VI and VII tended to have their ages-at-death overestimated by 4.25 years (males phase VII) to 5.87 years (females phase VII). Berg phases IV and V underestimated females' ages-at-death by 11.00 years and 9.90 years, respectively, while phases VI and VII overestimated ages-at-death by 8.16 years and 2.92 years, respectively (Table 4.10).

Table 4.8. Inaccuracy and bias of Suchey-Brooks (1990) phases.

	Phase	n =	Inaccuracy	Bias
Males	IV	32	13.21	-11.89
	V	103	14.19	-13.04
	VI	78	11.00	-8.30
Females	IV	9	10.09	-5.47
	V	59	16.52	-14.36
	VI	103	13.52	-8.86

Table 4.9. Inaccuracy and bias of Hartnett (2010a) phases.

	Phase	n =	Inaccuracy	Bias
Males	III	1	9.47	-9.47
	IV	38	11.93	-7.57
	V	109	9.01	-5.07
	VI	49	10.06	-6.38
	VII	16	7.38	4.25
Females	IV	12	10.21	-3.99
	V	45	11.46	-6.42
	VI	74	11.71	5.69
	VII	40	10.51	5.87

Table 4.10. Inaccuracy and bias of Berg (2008) phases.

	Phase	n =	Inaccuracy	Bias
Females	IV	4	13.25	-11.00
	V	20	13.05	-9.90
	VI	45	13.99	8.16
	VII	102	11.12	2.92

Comparison of various age intervals' inaccuracy and bias scores is necessary, because certain age intervals may consistently have their ages-at-death over- or underestimated by a method's phase means. Inaccuracy and bias scores for ten-year age intervals were calculated for males and females using the Suchey-Brooks (1990), Hartnett (2010a), and Berg (2008) methods (Tables 4.11 and 4.12). Inaccuracy values for ten-year age intervals of males using the Suchey-Brooks method range from 5.81 years (males aged 26-39 years) to 26.15 years (males aged 80-89 years) (Table 4.11). The range of inaccuracy values for ten-year age intervals of males using the Hartnett method was similar: 4.96 years (males aged 50-59 years) to 19.38 years (males aged 80-89 years). On average, Suchey-Brooks phase means overestimated the ages-at-death of males aged 26-39 years and underestimated the ages-at-death of males aged 40-89 years. In general, the phase means published by Hartnett overestimated the ages-at-death of males aged 26-49 years and underestimated the ages-at-death of males aged 50-89 years. Bias values indicate that Suchey-Brooks phase means overestimated the ages-at-death of all males aged 26-35 years (3.8% of sampled males), while Hartnett phase means overestimated the ages of all males aged 26-38 years (4.7% of sampled males). Conversely, Suchey-Brooks phase means underestimated the ages of all males aged 62-89 years (50.7% of sampled males), and Hartnett phase means underestimated the ages-at-death of all males aged 75-89 years (14.1% of sampled males).

Table 4.11. Inaccuracy and bias scores for males using the Suchey-Brooks (1990) and Hartnett (2010a) methods per ten-year age interval.

		Inaccuracy		Bias	
Age Interval	**n =**	**Suchey-Brooks**	**Hartnett**	**Suchey-Brooks**	**Hartnett**
26-39	14	5.81	11.56	3.53	10.21
40-49	29	6.66	6.11	-3.54	3.25
50-59	53	10.05	4.96	-7.24	-0.48
60-69	60	13.92	10.43	-13.92	-8.26
70-79	40	16.36	12.47	-16.36	-11.47
80-89	17	26.15	19.38	-26.15	-19.38

The Suchey-Brooks (1990) method yielded inaccuracy values for ten-year age intervals of females that ranged from 5.97 years (females aged 50-59 years) to 33.10 years (females aged 90-97years) (Table 4.12). Inaccuracy scores using the Hartnett (2010a) method ranged from 7.40 years (females aged 70-79 years) to 18.22 years (females aged 29-39 years). The Berg (2008) method produced inaccuracy values that ranged from 5.99 years (females aged 70-79 years) to 25.31 years (females aged 29-39 years). Overall, Suchey-Brooks phase means underestimated the ages-at-death of females aged 29-49 years and overestimated the ages-at-death of females aged 50-97 years. The phase means published by Hartnett and Berg both typically overestimated the ages-at-death of females aged 29-69 years and underestimated the ages-at-death of females aged 70-97 years. Bias values indicate that phase means for the Suchey-Brooks, Hartnett, and Berg methods overestimated the ages-at-death of all females aged 29-45 years (9.4% of sampled females). Brooks and Suchey's phase means underestimated the ages of all females aged 61-97 years (62.6% of sampled females), while Hartnett's underestimated the ages of all females aged 82-97 years (15.2% of sampled females) and

Berg's underestimated the ages of all females aged 74-97 years (32.7% of sampled females).

Table 4.12. Inaccuracy and bias scores for females using the Suchey-Brooks (1990), Hartnett (2010a), and Berg (2008) methods per ten-year age interval.

		Inaccuracy			**Bias**		
Age Interval	**n =**	**Suchey-Brooks**	**Hartnett**	**Berg**	**Suchey-Brooks**	**Hartnett**	**Berg**
29-39	7	11.43	18.22	25.31	11.43	18.22	25.31
40-49	20	9.55	11.65	17.88	6.62	10.33	15.58
50-59	32	5.97	11.81	12.75	-0.78	7.34	11.14
60-69	45	8.08	11.16	9.44	-8.08	5.55	5.18
70-79	34	18.94	7.40	5.99	-18.94	-2.22	-4.39
80-89	23	28.61	12.92	13.82	-28.61	-12.52	-13.82
90-97	10	33.10	13.62	18.90	-33.10	-13.62	-18.90

Paired t-tests were used to examine the significance of the differences between inaccuracy and bias values obtained using the methods tested in the present study. The inaccuracy and bias values listed for each method in Tables 4.13-4.15 are the average inaccuracy or bias scores among sampled individuals using that method. The two inaccuracy or bias scores for each individual, one from each of two methods, are the "pairs" that are tested using the paired t-test. The means listed in Tables 4.13-4.15 are calculated by taking the average of the differences between the pairs, and the standard deviations listed are the standard deviations from those means. The p-values represent the statistical significance of the differences between the paired inaccuracy or bias scores for the two methods tested. A p-value of $p<0.05$ is generally accepted as an indication of a statistically significant difference.

There were statistically significant differences in the Suchey-Brooks (1990) and Hartnett (2010a) inaccuracy and bias scores for males, females, and both sexes combined (Table 4.13). In each case, the Hartnett method had inaccuracy and bias values that were closer to zero than the Suchey-Brooks method. Inaccuracy and bias scores using the Suchey-Brooks and Berg (2008) methods for females were significantly different (Table 4.14). The Berg method yielded inaccuracy and bias scores that were nearer to zero than those produced by the Suchey-Brooks method. The differences between the inaccuracy and bias scores for the Hartnett and Berg methods were statistically insignificant (Table 4.15). Thus, the Hartnett method was less inaccurate and biased than the Suchey-Brooks method when analyzing male individuals, while the Hartnett and Berg methods were both less inaccurate and biased than the Suchey-Brooks method for females. These conclusions confirm the findings of the analyses of ten-year age intervals (Tables 4.11 and 4.12).

Table 4.13. Comparison of inaccuracy and bias in the Suchey-Brooks (1990) and Hartnett (2010a) methods for males and females.

		n =	Suchey-Brooks	Hartnett	Mean	SD	t-score	p =
Total	Inaccuracy	384	13.54	10.37	3.18	9.90	6.28	<0.001
	Bias	384	-10.89	-2.02	-8.87	8.73	-19.90	<0.001
Males	Inaccuracy	213	12.87	9.65	3.22	6.94	6.78	<0.001
	Bias	213	-11.13	-5.14	-6.00	6.91	-12.67	<0.001
Females	Inaccuracy	171	14.38	11.26	3.12	12.68	3.22	0.002
	Bias	171	-10.58	1.87	-12.45	9.44	-17.24	<0.001

Table 4.14. Comparison of inaccuracy and bias in the Suchey-Brooks (1990) and Berg (2008) methods for females.

	n =	Suchey-Brooks	Berg	Mean	SD	t-score	p =
Inaccuracy	171	14.38	12.15	2.23	12.53	2.32	0.021
Bias	171	-10.58	2.47	-12.81	25.56	-6.55	<0.001

Table 4.15. Comparison of inaccuracy and bias in the Berg (2008) and Hartnett (2010a) methods for females.

	n =	Berg	Hartnett	Mean	SD	t-score	p =
Inaccuracy	171	12.15	11.26	0.89	8.24	1.41	0.160
Bias	171	2.47	1.87	0.61	9.85	0.80	0.423

Inter- and Intra-Observer Agreement

A weighted Kappa statistic was used to evaluate inter- and intra-observer agreement (Tables 4.16 and 4.17) (Landis and Koch 1977). The weights increased according to the level of disagreement between the first and second observations (Table 4.16). For example, if the first observer assigned an individual to phase V, and the second observer scored the same individual as a phase VI, then the weight of that disagreement would be 1, because the observers' scores were one phase apart. The Hartnett (2010a) method resulted in the most inter-observer agreement, with a weighted Kappa of 0.372 (Table 4.17). Inter-observer agreement was similar for the Suchey-Brooks (1990) method at K=0.355, while there was less inter-observer agreement with the Berg (2008) method, where K=0.237. Intra-observer agreement was greater than inter-observer agreement for all three methods. The Berg method resulted in the highest intra-observer agreement with K=0.562, while the Suchey-Brooks and Hartnett methods followed with K=0.533 and K=0.489, respectively.

Table 4.16. Weights used to calculate the weighted Kappa statistic.

		1st Observation				
	Phase	**III**	**IV**	**V**	**VI**	**VII**
	III	0	1	2	3	4
	IV	1	0	1	2	3
2nd Observation	**V**	2	1	0	1	2
	VI	3	2	1	0	1
	VII	4	3	2	1	0

Table 4.17. Weighted Kappa statistic to determine inter- and intra-observer error.

	Suchey-Brooks	**Hartnett**	**Berg**
Inter-observer Kappa	0.355	0.372	0.237
Intra-observer Kappa	0.533	0.489	0.562

Trends in inter- and intra-observer agreement are visible upon examination of the tables used to calculate the weighted Kappa statistics (Tables 4.18-4.20) (Kimmerle *et al.* 2008b). The Hartnett (2010a) method resulted in the highest rate of inter-observer agreement, because although observers disagreed by one phase for half of the individuals in the sample, only three assessments (7.5%) diverged by two phases (Table 4.19). The author and the second observer agreed or were within one phase of each other's phase assignments for 85% of the individuals in the sample using both the Suchey-Brooks (1990) and Berg (2008) methods (Tables 4.18 and 4.20). One assessment (5%) using the Berg method and six observations (15%) using the Suchey-Brooks method differed by two phases. However, it was the two assignments (10%) that differed by three phases using the Berg method which caused the low inter-observer Kappa statistic (Tables 4.16 and 4.20). Intra-observer Kappa statistics follow the number of observations that disagreed by two phases: zero with the Berg method, one observation (1.7%) using the

Suchey-Brooks method, and two observations (3.4%) using the Hartnett method (Tables 4.16-4.20).

Table 4.18. Frequency of Suchey-Brooks (1990) phase assignments comparing the author's initial scores (Author 1) to the author's intra-observer scores (Author 2) and the second observer's scores.

		Author 1			
	Phase	**III**	**IV**	**V**	**VI**
Author 2	**III**				
	IV		3	2	
	V		7	21	3
	VI		1	5	16
2nd Observer	**III**	0	1	1	
	IV		1	4	5
	V		1	11	5
	VI				11

Table 4.19. Frequency of Hartnett (2010a) phase assignments comparing the author's initial scores (Author 1) to the author's intra-observer scores (Author 2) and the second observer's scores.

		Author 1				
	Phase	**III**	**IV**	**V**	**VI**	**VII**
Author 2	**III**	0				
	IV		3	3		
	V	1	9	18	4	
	VI		1	5	8	2
	VII					4
2nd Observer	**III**					
	IV		1	9	2	
	V		2	6	4	
	VI		1	2	7	2
	VII				1	3

Table 4.20. Frequency of Berg (2008) phase assignments comparing the author's initial scores (Author 1) to the author's intra-observer scores (Author 2) and the second observer's scores.

		Author 1			
	Phase	**IV**	**V**	**VI**	**VII**
Author 2	**IV**	0			
	V	1	2	1	
	VI		4	3	2
	VII			2	11
2nd Observer	**IV**	0	2	1	2
	V		1	4	
	VI			0	6
	VII				4

Tables 4.18-4.20 also reveal the phases in each method that are most subject to inter- and intra-observer disagreement (Kimmerle *et al.* 2008b). Observers may not be consistent in the criteria they feel are most important in assigning individuals to certain phases, or the same observer may contradict a previous score upon examining an individual a second time. Calculating the proportion of sampled individuals who are assigned first, for example, to phase V and then to phase VI as well as other individuals whose assignments are the opposite shows which phase transitions are most consistently confused. Inter- and intra-observer assessments of the Suchey-Brooks (1990) method showed that similar proportions of individuals in the transition from phase IV to V are confused as those in transition from phase V to VI (Table 4.18). Observers using the Hartnett (2010a) method displayed the most disagreement between phases IV and V, some between phases V and VI, but very few disagreements between phases VI and VII (Table 4.19). This indicates that observers agree about which individuals appear the "oldest," while individuals who fall in the middle phases are less consistently scored.

The results shown in Table 4.20 for the Berg method have the opposite trend: there were fewer disagreements between phases IV and V but more between phases V and VI and between phases VI and VII.

According to Landis and Koch's (1977:165) "strength of agreement" designations, weighted Kappa statistics indicate that there was "moderate" intra-observer agreement and "fair" inter-observer agreement. Unfortunately, the weighted Kappa statistics are somewhat low for inter- and intra-observer agreement, but this is not an uncommon problem in the field of adult age estimation (Kimmerle *et al.* 2008b). Kimmerle *et al.* (2008b:594) did not investigate the effect inter-observer disagreement had on the accuracy of age estimates, but they reported that the "wide range of variation, even among experienced investigators in the assignment of phase or metric data," appeared to stem from "the qualitative nature of broad descriptive phase categories, which contain multiple skeletal features and traits that are open to interpretation." In this context, fair or moderate rates of observer agreement are to be expected in assessments of adult age estimation methods such as the present study.

CHAPTER 5: DISCUSSION

Advantages and Disadvantages of Each Method

An adult age estimation method should be able to accurately predict the ages-at-death of individuals with similar socioeconomic backgrounds, ancestral groups, and ages-at-death to those in the reference sample. Hartnett's (2010a) and Berg's (2008) phase means are nearer to the phase means obtained using the study sample than to Brooks and Suchey's (1990) phase means, which indicates that the new methods better reflect the age structure of the study sample (Figures 4.1-4.3 and Tables 4.1-4.3, 4.8-4.10, and 4.13-4.15). The study sample is older on average than the reference sample employed by Brooks and Suchey (1990:229), as evidenced by the elevated phase means for each phase in the present study and the relative paucity of individuals aged over 65 years in the reference sample (Figures 2.1, 3.2, and 4.1 and Table 4.1). The consistent underestimation of individuals' ages-at-death using the Suchey-Brooks method is likely due in part to the age structure of the present study sample, which is predominately made up of older individuals whose bodies were donated after the individuals' natural deaths (UTK 2014). Autopsy samples such as those employed by Brooks and Suchey (1990) and Hartnett (2010a, b) include individuals of all ages whose bodies are examined by medical examiners to determine the cause and manner of death. Accidental deaths are not restricted to any section of the population, while homicides, suicides, drug overdoses, etc., are seen more frequently in certain age, ancestral, or socioeconomic groups (Murphy *et al.* 2013).

The present study yielded wide age intervals and large standard deviations for the phases of all three methods (Tables 4.1-4.3). This analysis indicates that there is substantial individual variation in the timing and rate of age-related morphological changes at the pubic symphysis. The 100% phase age intervals obtained in the present study are wide using all three methods; they range from 30 years (Suchey-Brooks females phase IV and Berg phase IV) to 60 years (Suchey-Brooks females phases V and VI and Hartnett females phase V). The standard deviations yielded by the present study are similar across the three methods: 9.90-14.53 years for Suchey-Brooks, 8.36-13.86 years for Hartnett, and 9.29-14.27 years for Berg. While this range of standard deviations is similar to those published by Brooks and Suchey (9.4-14.6 years), Hartnett's and Berg's published standard deviations were small by comparison: 3.94-9.33 years and 3.8-10.9 years, respectively. The standard deviations published by Brooks and Suchey therefore seem to account better for the large amount of variation at the pubic symphysis (Klepinger *et al.* 1992).

Another manifestation of individual variation is the extensive overlap of phase age intervals in many age estimation methods (Figures 2.1 and 4.1-4.3) (Brooks and Suchey 1990; Buckberry and Chamberlain 2002; Hartnett 2010a, b; İşcan *et al.* 1984b, 1985). In this respect, the results of the present study confirm the findings of previous studies. The nine females in Brooks and Suchey's (1990) phase IV were all within the 100% age interval of females in phase V (Figure 4.1). Likewise, the sixteen males in Hartnett's (2010a) phase VII were all within the 100% age interval of males in phase VI (Figure 4.2). The means, medians, 100% age intervals, and middle 50% age intervals of individuals in Berg’s (2008) phases V and VI are extremely similar (Figure 4.3). These results indicate that individuals in a certain age interval can be assigned to one of multiple phases. For example, females aged 50-60 years in the present study were assigned to Suchey-Brooks phases IV-VI, Hartnett phases IV-VII—although the three individuals in phase VII aged 50-60 years were in fact aged 56-60 years—and Berg phases IV-VII (Figures 4.1-4.3 and Tables 4.1-4.3).

The ability of a method to “correctly” estimate the age of an individual was measured by the percentage of individuals whose recorded ages-at-death fell within the age interval of their assigned phase or within two standard deviations of the phase mean. The Suchey-Brooks (1990) and Hartnett (2010a) methods estimated males’ ages-at-death equally well, with 87.8% of individuals falling within the 95% intervals published by Brooks and Suchey and the 100% intervals published by Hartnett (Tables 4.4 and 4.5). Nearly equal percentages of males were within two standard deviations of Brooks and Suchey’s as well as Hartnett’s phase means: 84.5% and 85.0%, respectively. In total, 82.5% of females were within two standard deviations of Brooks and Suchey’s phase means, while 78.4% and 68.4% were within two standard deviations of Berg’s and Hartnett’s phase means, respectively (Tables 4.4-4.6). However, in Table 4.7 it is apparent that around the age of 70 years the Berg method begins to yield the highest percentages of correct estimates out of the three methods examined in the present study. Of the 67 females aged 70-97 years, 91.0% were within two standard deviations of Berg’s phase means, while 79.1% and 56.7% were within two standard deviations of Hartnett’s and Brooks and Suchey’s phase means, respectively. The Suchey-Brooks method was best for females aged 29-69 years, with 99.0% of individuals falling within two standard deviations of the phase means, while the Berg and Hartnett methods followed with 70.2% and 61.5%, respectively. Thus, when examining the rates of "correct" age estimates both the Suchey-Brooks and Hartnett methods estimate the ages-at-death of adult males well, young or middle-aged adult females are best assessed using the Suchey-Brooks method, and elderly females are best examined using the Berg method. In practice, however, age estimation methods are not applied to individuals whose ages-at-death are already known. Therefore, females whose skeletons do not display indicators of advanced age should be examined using the Suchey-Brooks method, while female skeletons with indicators of advanced age such as degenerative joint disease should be analyzed using the Berg method.

The rates of inaccuracy and bias were calculated for each method overall as well as for males, females, observed phases of each method, and ten-year age intervals (Tables 4.8-4.12). Inaccuracy measures the absolute distance of individuals' recorded ages from the published mean of their assigned phase (Hens *et al.* 2008; Lovejoy *et al*. 1985a, b; Merritt 2014; Murray and Murray 1991; Schmitt 2004). Bias measures the distance of individuals' recorded ages above or below their phase mean to reveal methods' tendencies to over- or underestimate age-at-death. Paired t-tests were conducted to reveal significant differences between the scores calculated for each method (Kimmerle *et al.* 2008b; Merritt 2014). Low inaccuracy scores and bias scores approaching zero indicate that a method is accurate and does not substantially over- or underestimate individuals' ages-at-death.

The Hartnett (2010a) method was significantly less inaccurate and biased than the Suchey-Brooks (1990) method when estimating males' ages-at-death (Table 4.13). Inaccuracy and bias scores for males were both significantly different at a p= 0.001 level, with both of Hartnett's scores closer to zero than Suchey-Brooks' scores. In Table 4.11 it is evident that at and above the 50-59 year age interval Hartnett's scores are consistently better than Suchey-Brooks'. However, the two methods' scores are similar for the 40-49 year age interval, and Suchey-Brooks scores are better for individuals in the 26-39 year age interval. Separate inaccuracy and bias scores were calculated for males aged 26-49 years and those aged 50-89 years to ascertain the utility of the two methods for males aged above and below 50 years (Tables 5.1 and 5.2). The Suchey-Brooks method yielded a slightly lower inaccuracy score than the Hartnett method for males aged 26-49 years, although the difference was not statistically significant (Table 5.1). Bias scores for this age interval were statistically significant at a p= 0.001 level, with the Suchey-Brooks method scoring closer to zero than the Hartnett method (Table 5.2). Inaccuracy and bias scores for males aged 50-89 years were significantly different at a p= 0.001 level, with the Hartnett method scoring closer to zero than the Suchey-Brooks method in both cases (Tables 5.1 and 5.2). Thus, the Suchey-Brooks method is less biased and slightly less inaccurate than the Hartnett method for males aged less than 50 years, while the Hartnett method is less inaccurate and biased for males aged 50 years and greater.

Table 5.1. Inaccuracy scores for males aged less than 50 years and 50 years or greater using the Suchey-Brooks (1990) and Hartnett (2010a) methods.

Age Interval	n =	Suchey-Brooks	Hartnett	p =
26-49	43	6.39	7.88	0.103
50-89	170	14.51	10.10	<0.001

Table 5.2. Bias scores for males aged less than 50 years and 50 years or greater using the Suchey-Brooks (1990) and Hartnett (2010a) methods.

Age Interval	n =	Suchey-Brooks	Hartnett	p =
26-49	43	-1.24	5.51	<0.001
50-89	170	-13.63	-7.83	<0.001

When estimating the ages-at-death of adult females, the Hartnett (2010a) and Berg (2008) methods are significantly less inaccurate and biased than the Suchey-Brooks method, although they do not differ significantly from each other (Tables 4.13-4.15). According to Table 4.12, at and above the 60-69 year age interval Hartnett's and/or Berg's inaccuracy and bias scores are consistently similar to or better than Brooks and Suchey's scores. Therefore, each method's inaccuracy and bias scores for females aged 29-59 years and those aged 60-97 years were calculated and compared. The Suchey-Brooks method yielded the inaccuracy and bias scores nearest zero for females aged 29-59 years, followed by the Hartnett and then Berg methods (Tables 5.3 and 5.5). Each method's inaccuracy and bias scores were significantly different than every other method's scores for females aged 29-59 years. There was no significant difference between Hartnett's and Berg's inaccuracy scores for females aged 60-97 years, but both scored significantly lower than the Suchey-Brooks method (Tables 5.3 and 5.4). The bias score closest to zero for females aged 60-97 years was obtained using the Hartnett method (Table 5.5). The difference between Hartnett's and Berg's bias scores approached statistical significance but was not significant at a p= 0.05 level (Table 5.6). However, the Hartnett and Berg methods were significantly less biased than the Suchey-Brooks method for females aged 60-97 years. Therefore, the Suchey-Brooks method is the least inaccurate and biased method for estimating the ages-at-death of females aged 29-59 years, while the Hartnett and Berg methods are both less inaccurate and biased than the Suchey-Brooks method for females aged 60-97 years.

Table 5.3. Inaccuracy scores for females aged less than 60 years and 60 years or greater using the Suchey-Brooks (1990), Hartnett (2010a), and Berg (2008) methods.

Age Interval	n =	Suchey-Brooks	Hartnett	Berg
29-59	59	7.83	12.52	15.98
60-97	112	17.83	10.60	10.14

Table 5.4. Statistical significance of the differences between inaccuracy scores for females aged less than 60 years and 60 years or greater using the Suchey-Brooks (1990), Hartnett (2010a), and Berg (2008) methods.

Age Interval	n =	Suchey-Brooks v. Hartnett	Suchey-Brooks v. Berg	Berg v. Hartnett
29-59	59	<0.001	<0.001	0.007
60-97	112	<0.001	<0.001	0.496

Table 5.5. Bias scores for females aged less than 60 years and 60 years or greater using the Suchey-Brooks (1990), Hartnett (2010a), and Berg (2008) methods.

Age Interval	n =	Suchey-Brooks	Hartnett	Berg
29-59	59	3.17	9.64	14.33
60-97	112	-17.83	-2.23	-3.78

Table 5.6. Statistical significance of the differences between bias scores for females aged less than 60 years and 60 years or greater using the Suchey-Brooks (1990), Hartnett (2010a), and Berg (2008) methods.

Age Interval	n =	Suchey-Brooks v. Hartnett	Suchey-Brooks v. Berg	Berg v. Hartnett
29-59	59	<0.001	<0.001	0.001
60-97	112	<0.001	<0.001	0.066

Observers using an age estimation method should be able to consistently arrive at the same conclusion when examining the same individuals. The rates of intra-observer agreement calculated using a weighted Kappa statistic were similar using the Suchey-Brooks (1990), Hartnett (2010a), and Berg (2008) methods (Table 4.17). According to Landis and Koch's (1977:165) "strength of agreement" designations, all three methods show "moderate" intra-observer agreement. Rates of inter-observer agreement were similar using the Suchey-Brooks and Hartnett methods, while the Berg method had a lower rate of inter-observer agreement (Table 4.17). However, the rates of inter-observer error for the three methods fall into Landis and Koch's "fair" category. Due to the wide age intervals and/or large standard deviations published with the three methods examined by the present study the percentages of "correct" age-at-death estimates may not be substantially affected by somewhat low rates of inter- or intra-observer agreement (Kimmerle *et al.* 2008b).

Relative Utility of Phase Descriptions

Certain unique descriptions are helpful in differentiating the phases of each method, while other descriptors are subjective or difficult to employ. All three methods examined in the present study included somewhat subjective descriptions of the degree of dorsal lipping, which could be slight, moderate, or pronounced, although Berg (2008) found dorsal lipping to be quite variable in phase VII. Similarly, Berg and Hartnett (2010a) mention the weight or quality of the bone, which they use as a key deciding factor between their phases VI and VII. A bone that feels lightweight is likely from an older individual whose bone density has decreased with age, so extremely lightweight bones should be assigned to phase VII (Berg 2008; Hartnett 2010a). The lightweight or brittle feel of a bone is not quantifiable and is therefore rather subjective, but with experience an observer can distinguish moderately or extremely lightweight bones from normal or slightly lightweight bones.

Some elements of the new methods' phase descriptions are problematic. Hartnett (2010a) describes the texture changes of the surface of the pubic bone, which in young adults is smooth and dense but begins to feel like sandpaper with increased age. In the text of her article, Hartnett (2010a:1148-9) defines this sandpaper-like texture using the words "rough" and "coarse" interchangeably, but the phase descriptions appear make a distinction between the two terms. For example, bone texture in phase IV is "roughened and becoming coarse," and bones in phase VI feel "rough and coarse" (Hartnett 2010a:1151). It is possible to tell the difference between smooth bone and slight, moderate, and pronounced roughness, but the shifts from one stage to the next are subtle and are not explained further in Harnett's phase descriptions. Berg's (2008) phase descriptions rely on the ability of an observer to estimate the percentage of the symphyseal face that is affected by porosity. His phases V and VI are differentiated by estimating if less than or greater than 15% of the symphyseal face is made up of porous bone. Berg allows the use of a handheld magnifying glass, but the small size of the symphyseal face and the individual variation associated with the location of porosity results in difficulty estimating a percentage that can be compared to the phase descriptions.

Selected parts of phase descriptions from each of the methods studied were particularly helpful in describing morphological changes to the pubic symphysis. All three methods note that rim breakdown begins at the superior aspect of the ventral margin of the symphyseal face, although for an inexperienced observer a hiatus may appear similar to rim breakdown due to its location. Hartnett (2010a:1149-51) distinguishes a ventral hiatus in phase IV from rim breakdown in phase V by specifying that rim breakdown "appears as irregular bone (not rounded/solid)." The authors of the three methods use different terminology to describe age-related changes occurring on the ventral surface of the pubic bone. Brooks and Suchey (1990:233) as well as Berg (2008:577) refer to "ligamentous outgrowths," while Hartnett (2010a:1151) calls this phenomenon "bony buildup" which may be "elaborate and proliferative" at the pubic tubercle and the ventral arc. Berg (2008:577) adds that in phase VII, osteoporosis may cause the ventral surface of the pubis to appear "scarred" or "striated." Berg (2008:574) also explains that macroporosity on the symphyseal face may begin as "coalescences of smaller porosities into oblong pores/channels." All three methods agree that an initial sign of degeneration after the symphyseal rim or outline is completed is the slight depression of the face. In Brooks and Suchey's (1990:233) phase VI, the "face shows ongoing depression as [the] rim erodes," but by Berg's (2008:577) phase VII "[t]he symphyseal face appears to be relatively flat, since the rim is highly eroded and is losing definition." Hartnett's and Berg's addition of a phase VII allows observers to take into account extensive degeneration of the pubic symphysis in older individuals.

Comparison of the Present Study to Merritt's (2014) Validation Study of Hartnett (2010a)

Merritt (2014) recently published a validation study similar to the present study in which she examined Hartnett's (2010a, b) revisions of the Suchey-Brooks (1990) and İşcan *et al.* (1984b) age estimation methods. Comparisons of Merritt's (2014) results and the results obtained in the present study reveal the pros and cons of the Suchey-Brooks and Hartnett methods. Merritt (2014) examined 322 individuals (230 males, 92 females) from the William M. Bass Donated Skeletal Collection, which facilitates comparisons between her study and the present study due to the similarity of the samples. Merritt calculated the percentages of "correct" age estimates, rates of inaccuracy and bias, the correlation between actual age at death and the mean age at death within each phase, and the rate of intra-observer error using a sample of thirty individuals. The results of the present study are generally similar to Merritt's results, with some minor disagreements.

"Correctness"

Merritt (2014) found that the Suchey-Brooks (1990) method "correctly" estimated the ages-at-death of more individuals than the Hartnett (2010a) method. The results of the present study agree with this conclusion (Tables 4.4 and 4.5). Merritt's (2014) definition of "correct" was different than the definitions employed by the present author, so new calculations were performed allow direct comparisons of percentages of correct estimates (Table 5.7). Merritt (2014) defined “correct” for individuals aged less than 60 years as within one standard deviation of the mean of an individual’s assigned phase. Individuals aged over 60 years had their ages-at-death estimated “correctly” if they were assigned to Suchey-Brooks phase VI or to Hartnett phases VI or VII. Merritt (2014) emphasizes that her use of a single standard deviation to calculate correctness was intended to minimize phase overlap and to assess “how well the mean age at death of a phase represents the individuals assigned to that particular age category; it [was] not a reflection of the method’s correctness as whole” (2014:707).

Merritt (2014) and the present study both found that the Suchey-Brooks (1990) method “correctly” estimated the ages-at-death of significantly more females than males. Using Merritt’s (2014) definition of “correct,” the present study found that the Hartnett method is better for females than for males, while Merritt arrived at the opposite conclusion (Table 5.7). However, using Hartnett’s published 100% age intervals or ± one or two standard deviations from individuals’ assigned phase means, that method yielded more correct estimates for males than females (Table 4.5). The present study found that the percentages of correct estimates for males using the Suchey-Brooks and Hartnett methods were 61.0% and 58.7%, respectively, when employing Merritt’s (2014) definition of “correct,” while her percentages were 67.4% and 61.3%, respectively(Table 5.7). Using Brooks and Suchey’s and Hartnett’s published age intervals or ± one or two standard deviations from the phase means, the two methods yielded virtually identical or very similar percentages of correct age estimates for males (Tables 4.4 and 4.5). Merritt

(2014) found that the Suchey-Brooks method yielded more correct age estimates for all ten-year age intervals, while the present study found that Hartnett's percentages were higher for males aged greater than 50 years and for females aged greater than 70 years (Tables 4.7 and 5.8). Merritt concluded that Hartnett's phase means represented the recorded ages-at-death of the individuals in her sample better than the means published for the Suchey-Brooks method. The results of the present study confirm her findings in this respect (Figures 4.1 and 4.2 and Tables 4.1 and 4.2).

Table 5.7. Percentages of correct classifications for each sex according to Merritt's (2014) definition of "correct" using the Suchey-Brooks (1990) and Hartnett (2010) methods.

	Merritt (2014)			Present Study		
	n =	**Suchey-Brooks**	**Hartnett**	**n =**	**Suchey-Brooks**	**Hartnett**
Males	230	67.4%	61.3%	213	61.0%	58.7%
Females	92	79.3%	50.0%	171	74.9%	64.3%
Total	322	70.8%	58.1%	384	67.2%	61.2%

Table 5.8. Percentages of correct classifications per 10-year age interval according to Merritt's (2014) definition of "correct" using the Suchey-Brooks (1990) and Hartnett (2010) methods.

	Merritt (2014)			Present Study		
Age Interval	**n =**	**Suchey-Brooks**	**Hartnett**	**n =**	**Suchey-Brooks**	**Hartnett**
18-29	7	100.0%	57.1%	2	50.0%	0.0%
30-39	23	73.9%	47.8%	19	78.9%	26.3%
40-49	62	72.6%	64.5%	49	65.3%	63.3%
50-59	81	79.0%	63.0%	85	78.8%	61.2%
60-69	71	56.3%	49.3%	105	51.4%	48.6%
70-79	53	67.9%	62.3%	74	71.6%	77.0%
80-89	24	75.0%	50.0%	40	65.0%	72.5%
90-99	1	100.0%	100.0%	10	100.0%	100.0%

Inaccuracy and Bias

Merritt (2014) and the present study agree that the Hartnett (2010a) method was significantly less inaccurate and biased than the Suchey-Brooks (1990) method (Table 5.9). The present study found that there were no significant differences in Brooks and Suchey's and Hartnett's inaccuracy scores for individuals aged 40-69 years (Table 5.10). Merritt's (2014) analysis of inaccuracy scores found that differences approached statistical significance at a $p= 0.05$ level for individuals aged 40-49 years ($p= 0.065$), were insignificant for individuals aged 50-59 years, and were statistically significant at a $p= 0.01$ level for individuals aged 60-69 years (Table 5.10). Merritt (2014) and the present study agree that the only age interval in which the Suchey-Brooks method yielded significantly lower inaccuracy scores than the Hartnett method was for individuals aged 30-39 years. However, the present study found that the Suchey-Brooks and Hartnett methods' inaccuracy scores for males aged 26-49 years were not statistically significant, while the Suchey-Brooks method was significantly less inaccurate for females aged 29-59 years (Tables 5.1, 5.3, and 5.4).

Table 5.9. Comparison of inaccuracy and bias scores calculated by Merritt (2014) and the present study for the Suchey-Brooks (1990) and Hartnett (2010) methods.

		Merritt (2014)				Present Study			
		n =	Suchey-Brooks	Hartnett	p =	n =	Suchey-Brooks	Hartnett	p =
Total	Inaccuracy	322	11.55	9.02	<0.001	384	13.54	10.37	<0.001
	Bias	322	-8.43	0.56	<0.001	384	-10.89	-2.02	<0.001
Males	Inaccuracy	230	10.82	8.66	<0.001	213	12.87	9.65	<0.001
	Bias	230	-7.67	-0.38	<0.001	213	-11.13	-5.14	<0.001
Females	Inaccuracy	92	13.38	9.91	0.003	171	14.38	11.26	0.002
	Bias	92	-10.34	2.92	<0.001	171	-10.58	1.87	<0.001

Table 5.10. Comparison of inaccuracy scores calculated by Merritt (2014) and the present study for both sexes using the Suchey-Brooks (1990) and Hartnett (2010) methods.

	Merritt (2014)				Present Study			
Age Interval	**n =**	**Suchey-Brooks**	**Hartnett**	**p =**	**n =**	**Suchey-Brooks**	**Hartnett**	**p =**
18-29	7	3.94	6.21	0.156	2	14.15	19.51	
30-39	23	5.97	10.83	<0.001	19	7.01	13.18	<0.001
40-49	62	6.95	8.57	0.065	49	7.84	8.37	0.586
50-59	81	8.75	7.77	0.262	85	8.51	7.54	0.332
60-69	71	11.41	8.78	0.002	105	11.42	10.74	0.453
70-79	53	17.84	9.83	<0.001	74	17.54	10.14	<0.001
80-89	24	26.17	12.34	<0.001	40	27.57	15.67	<0.001
90-99	1	32.00	9.46		10	33.10	13.62	<0.001

Merritt (2014) and the present study both found that the Suchey-Brooks (1990) method was significantly less biased than the Hartnett (2010a) method for individuals aged 30-49 years (Table 5.11). Both also found that there was a significant difference in the bias scores for individuals aged 50-59 years, although the bias scores calculated by Merritt for the two methods have nearly the same absolute values, while the present study found that Hartnett's score was closer to zero than Brooks and Suchey's. The results of the present study agree with Merritt's (2014:705) conclusion that "for individuals under the age of 50 years, the Suchey-Brooks method has significantly lower bias scores, while for individuals over the age of 50 years, the Hartnett method has significantly lower bias scores" (Tables 4.11, 4.12, and 5.11). This conclusion holds true for males (Tables 4.11 and 5.2), while the Suchey-Brooks method is less biased for females aged less than 60 years (Tables 4.12, 5.5, and 5.6)

Table 5.11. Comparison of bias scores calculated for both sexes using the Suchey-Brooks (1990) and Hartnett (2010) methods by Merritt (2014) and the present study.

	Merritt (2014)				Present Study			
Age Interval	**n =**	**Suchey-Brooks**	**Hartnett**	**p =**	**n =**	**Suchey-Brooks**	**Hartnett**	**p =**
18-29	7	1.03	4.05	0.147	2	14.15	19.51	
30-39	23	1.89	9.27	<0.001	19	5.32	12.18	<0.001
40-49	62	−0.67	5.91	<0.001	49	0.60	6.14	<0.001
50-59	81	−4.38	4.04	<0.001	85	-4.81	2.46	<0.001
60-69	71	−10.90	−1.96	<0.001	105	-11.42	-2.55	<0.001
70-79	53	−17.64	−6.18	<0.001	74	-17.54	-7.22	<0.001
80-89	24	−26.17	−11.66	<0.001	40	-27.57	-15.44	<0.001
90-99	1	−32.00	−9.46		10	-33.10	-13.62	<0.001

The most striking difference in the results obtained by Merritt (2014) and the present study are the rates of intra-observer error (Table 5.12). According to Landis and Koch's (1977:165) admittedly arbitrary "strength of agreement" designations, Merritt's values fall into the "almost perfect agreement" category while the values calculated for the present study fall into the "moderate agreement" category. This discrepancy may be due to differences in calculation techniques, sample size, observer experience, or observer bias. Merritt's (2014) intra-observer values for the Suchey-Brooks (1990) and

Hartnett (2010a) methods are virtually identical, while the present study found that the rate of intra-observer agreement for the Hartnett method was 0.044 less than the rate calculated for the Suchey-Brooks method (Table 5.12).

Table 5.12. Comparison of Merritt's (2014) and the present study's weighted Kappa statistics calculated for intra-observer agreement using the Suchey-Brooks (1990) and Hartnett (2010a) methods.

	n =	**Suchey- Brooks**	**Hartnett**
Merritt	30	0.913	0.918
Present Study	58	0.533	0.489

The results of the present study support previous studies' conclusions that there is a great deal of individual variation in the timing of age-related morphological changes to the pubic symphysis (Brooks and Suchey 1990; Hoppa 2000; Jackes 1985; Klepinger *et al.* 1992). The large standard deviations presented by Brooks and Suchey (1990) account for the high percentages of "correct" estimates obtained for the study sample using their method (Klepinger *et al.* 1992). Berg's (2008) and Hartnett's (2010a) methods yielded lower rates of inaccuracy and bias overall than the Suchey-Brooks method, possibly due to the inclusion of more elderly adults in the new methods' reference samples. The new methods' modified phase descriptions were helpful in most aspects but were occasionally problematic. Results of the present study are similar to those presented by Merritt's (2014) validation study of the Hartnett (2010a) method, although Merritt's rate of intra-observer agreement was higher than that obtained by the author for the present study.

CHAPTER 6: CONCLUSIONS

The present study examined 384 pubic symphyses to compare the utility of Berg's (2008) and Hartnett's (2010a) addition of a seventh phase to the Suchey-Brooks (1990) age estimation method for the pubic symphysis and their overall revisions of the method. The study sample was selected from the most recently donated White North Americans at the William M. Bass Donated Skeletal Collection at the University of Tennessee, Knoxville, TN, and consisted of 213 males and 171 females aged 26-97 years. Due to the composition of the Bass Collection and the focus of the present study on elderly individuals, 59.6% of the individuals in the study sample were aged greater than sixty years. Furthermore, the present study cannot comment on the utility of the methods for younger individuals in phases I-III, because all individuals were assigned to Suchey-Brooks phases IV-VI, all individuals except one male to Hartnett phases IV-VII, and all females to Berg phases IV-VII. Individuals' ages-at-death were estimated using the age intervals, means, and standard deviations published by Brooks and Suchey, Hartnett, and Berg. Descriptive statistics for the phases of each method examined were calculated for the study sample and compared to the published statistics. Percentages of "correct" estimates and inaccuracy and bias values were compared across the three methods by sex and age interval. A subsample of forty individuals was assessed by a second observer and inter-observer agreement was calculated using a weighted Kappa statistic. A second subsample of fifty-eight individuals was reexamined by the author to find the rate of intra-observer agreement. Finally, the results of the present study were compared to those published in a recent study by Merritt (2014), who compared the Suchey-Brooks and Hartnett methods.

Acceptance or Rejection of the Hypothesis

The hypothesis of the present study states that Berg's (2008) and/or Hartnett's (2010a) modifications to the Suchey-Brooks (1990) method and their addition of a seventh phase improve the existing method. In general the results of the present study support the hypothesis, although the Suchey-Brooks method is preferable for some age intervals. Intra-observer agreement was higher than inter-observer agreement for all three methods. According to Landis and Koch's (1977:165) designations, inter-observer agreement was "fair" for all three methods, while intra-observer agreement was "moderate." The Hartnett method yielded the highest inter-observer Kappa value while the Berg method yielded the highest intra-observer Kappa value.

The Hartnett (2010a) and Suchey-Brooks (1990) methods yielded similar percentages of correct estimates for males using published age intervals or ± one or ± two standard deviations from phase means. However, the Hartnett method was significantly less inaccurate and biased than the Suchey-Brooks method. The Suchey-Brooks method yielded a slightly higher percentage of correct estimates for males aged less than 50 years and was significantly less biased, although the two methods yielded similar inaccuracy values. Conversely, the Hartnett method yielded a slightly higher percentage of correct estimates for males aged greater than 50 years and was significantly less inaccurate and biased. Therefore, the results of the present study indicate that the Hartnett method improves the Suchey-Brooks method for males, particularly those aged greater than 50 years.

The Suchey-Brooks (1990) method yielded the highest percentage of “correct” age estimates for females, but the Berg (2008) and Hartnett (2010a) methods were significantly less inaccurate and biased. For females aged less than 60 years, the Suchey-Brooks method yielded the highest percentage of correct estimates and was significantly less inaccurate and biased than the Hartnett and Berg methods. The Berg method yielded the highest percentage of correct estimates for females aged greater than 60 years. Both Berg’s and Hartnett’s inaccuracy and bias values were significantly lower than Brooks and Suchey’s for this age interval, although they were not significantly different from each other. Hartnett’s relatively narrow age intervals and smaller standard deviations resulted in lower percentages of correct estimates than those yielded by the Suchey-Brooks and Berg methods. The author assigned 59.6% of females in the study sample to Berg’s phase VII in part due to his strict decision-making criteria. Berg assigned half of the females he examined at the Bass Collection to phase VII, so the results of the present study may be mimicking his results. This tendency to assign females to phase VII based on Berg’s decision-making criteria may be problematic given that the author assigned only 23.4% of females to Hartnett’s phase VII despite the similarity of their phase descriptions. Overall, the results indicate that the Berg method is the best method for estimating the ages-at-death of elderly females, while the unmodified Suchey-Brooks method remains the best for younger and middle-aged females.

Practitioners presented with skeletons of unknown ages-at-death should consider the advantages and disadvantages of each pubic symphysis age estimation method examined in the present study to select an appropriate method. Given that the individual's age is unknown, the presence or absence of gross indicators of advanced age such as osteoarthritis (Ortner 2003:545-558) or osteoporosis (Berg 2008; Ortner 2003:410-415) should be observed and recorded before making this decision. If these indicators are absent, then practitioners should continue to employ the Suchey-Brooks method due to its utility for adults in all age groups. If either is present then practitioners should use the Hartnett (2010a) method to estimate the ages-at-death of males and the Berg (2008) method to estimate the ages-at-death of females.

Subsequent research should focus on the application of the Hartnett (2010a) and Berg (2008) methods to non-White and non-American populations. The author assessed forty-two Black Americans (36 males and 6 females) at the William M. Bass Donated Skeletal Collection, and will compare the results of the present study to results obtained using the Black American sample in a future study. The utility of the Hartnett and Berg methods for historical and archaeological samples is also unknown. Due to the paucity of young adults in the Bass Collection, neither the present study nor Merritt (2014) adequately compared the Suchey-Brooks (1990) and Hartnett methods for individuals aged under forty years. The author recommends the creation of casts to accompany the Hartnett and Berg methods in future validation studies.

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CURRICULUM VITAE

Jasmine M. Cloven

Academics

- Enrolled in the Forensic Anthropology Master of Science program at Boston University

Course Title	Instructor	Grade
Zooarchaeology	Pokines	B+
Bioarchaeology	Bethard	A
Forensic Anthropology Techniques	Bethard	A
Forensic Pathology	Hammers, Cummings	A
Anatomy and Osteology	Siwek	A
Expert Witness Testimony	Powers	A
Outdoor Crime Scene Awareness	L'Italien	A
History of Biological Anthropology	Bethard	A
Forensic Anthropology Field Methods	Pokines	B+
Applied Forensic Anthropology	Pokines	A-
Advanced Crime Scene Awareness	Reineke	A-
Advanced Osteology	Bethard	A
Taphonomy	Pokines	B+
Mortuary Archaeology	Pokines	A-
Elementary Biostatistics	Joseph	B

- Graduated Magna Cum Laude from State University of New York-Binghamton in May 2012
    - Cumulative GPA: 3.756
    - Dean's List semesters: Fall 2008, Spring 2009, Spring 2010, Fall 2010, Spring 2011, Spring 2012
    - Bachelor of Science in Physical Anthropology
    - Bachelor of Arts in Spanish

Professional Associations

- American Association of Physical Anthropologists
    - Preliminary acceptance of student membership application pending a vote by the AAPA membership in April 2015
- Paleopathology Association
    - Member since September 2014

Honor Societies

- Phi Sigma Iota: The International Foreign Language Honor Society
    - Spanish language
    - Member since 2011
- Phi Beta Kappa
    - Member since 2012

Field and Laboratory Experience

- Huari-Ancash Bioachaeological Research Project Field School: June 2011
    - Director: Bebel Ibarra Asencios
    - Excavated a multiple burial on the edge of the amphitheater at the Marcajirca site located near the town of Huari, in the province of Ancash, Peru
- The Mammoth Site of Hot Springs, South Dakota: paid internship May-August 2010
    - Director: Larry Agenbroad, PhD.
    - 96 hours of excavation
        - Excavated, documented, and mapped bone fragments
    - 138 hours of bone preparation in the laboratory
        - Cleaned bones with dental picks, air scribe, and microjack
        - Pieced together broken bones
        - Removed old preservatives to apply new preservatives
        - Sorted through screened sediment
    - 256 hours of public outreach
        - Gave 10-20 tours of the site each week
        - Taught a children's "Junior Paleontology" class three times each week

Teaching Experience

- Gave an impromptu talk in Spanish to local schoolchildren who visited Marcajirca on a field trip
    - Explained the significance of the site
    - Identified and described sexually dimorphic features of the pelvis and cranium
    - Described the process of cranial modification that is frequently seen in individuals at Peruvian archaeological sites
- Gave visitors tours of the Mammoth Site
- Taught a “Junior Paleontology” class for children ages 4-12 at the Mammoth Site
- Tutored a student in ANTH200 (Quantitative Methods in Anthropology)

Technical Experience

- Trained to use Leica total station mapping combined with TDS Recon data logging equipment, using TDS Survey Pro software
- Proficient in Microsoft Excel, particularly in statistical data analysis and creating spreadsheets, tables, and graphs
- Proficient in Microsoft Word and PowerPoint

Research Interests in Forensic Anthropology

- Practical experimentation
    - Identification of a suitable model for human infants and children
- Child abuse
- Human rights
- Application of 3D imaging technologies
    - Analysis of living individuals using 3D imaging
- Trauma
- Pathology